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The evaluation of steam and high temperature water heating system alternatives for a naval air station.

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THE EVALUATION OF STEAM AND HIGH TEMPERATURE WATER HEATING SYSTEM ALTERNATIVES FOR A NAVAL AIR STATION

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THE EVALUATION OF STEAM AND HIGH TEMPERATURE WATER HEATING SYSTEM ALTERNATIVES FOR A NAVAL AIR STATION

by

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A Thesis Submitted to the Faculty

of the Department of Mechanical Engineering

in Partial Fulfillment of the

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Approved by:

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Advisor

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To my wife, Barbara, a sincere thank you for contributing many hours of time and patience devoted to typing and proof reading preliminary manuscripts.

FOREWORD

The necessity for new construction within the Naval Shore Establishment is a continuing phenomenon consistant with the Navy's expanding mission of maintaining the peace in the free world. All of this construction is directly supported by taxpayers' dollars. The Navy's primary mission of support to the fleet is facilitated every time a single dollar can be saved due to economies in construction that do not overly compromise maintenance or operating expenses.

When planning and designing for the construction of a major facility for the Naval Shore Establishment, the utilities are of prime importance and must receive thorough study from several view points, namely:

1. Actual load requirements
2. Duration of the requirement
3. Need for future expansion
4. Mobilization requirements
5. Sensitivity of the mission
6. Permanence of the facility
7. Stand-by requirements[24]*

When considering alternatives for providing heat over an extended area to many buildings, there are basically two means by which this may be accomplished. The first means is the generation of heat at a central plant and the supplying of this heat through a

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*Throughout this thesis, superscript numbers refer to the similarly numbered items in PART VII, LITERATURE CITED AND OTHER BIBLIOGRAPHY, used in support of statements preceding the superscript numbers.

distribution piping system. The heat transportation media is either high pressure steam or high temperature water (HTW). These two alternatives are considered in this evaluation. The second means for heating multiple buildings is by individual heating plants for each building or small group of buildings. Based on experience and study, the armed services have found that it is more desirable from an operational and maintenance viewpoint and more economical from a cost viewpoint to use a central heating plant rather than individual building heating plants for installations of the size considered as an alternative solution.

Considering high pressure steam or HTW, the system's operating temperatures and pressures are determined primarily by the nature of the load and principles of economy with one sizable additional influence factor being the availability of standard material and equipment such as schedule 40 pipe and package steam boilers or HTW generators.

Steam heating systems have been in use for many years and are well standardized with regard to materials, component equipment, and design. HTW is a heat distribution method not utilized to any great extent in this country until relatively recently. HTW has been used successfully for a number of heating installations similar to the one discussed in this study, but it is not as familiar to most people as the steam heating system. For these reasons this evaluation study will include the consideration for both high pressure steam and HTW heating system alternatives, however, the HTW heating system will be discussed and justified in more detail than the steam heating system where it seems necessary.

In the past few years there have been a large number of articles written by men prominent in the HTW field. These articles usually claim great economy for HTW over steam for certain types of installations including large heat distribution installations. In view of this publicity, the HTW alternative will be evaluated cautiously.

ABSTRACT

The purpose in preparing this study is to compare alternative solutions for a central heating plant and distribution system for a large, decentralized, predominately space heating load. The alternatives considered are high pressure steam and high temperature water (HTW) heat transporting media.

A realistic problem consisting of a large heating load distributed over a distance of several miles located on relatively level terrain serving a Naval Air Station is considered.

The design and evaluation for each alternative is supported by calculations. Since the HTW heating system alternative has received only recent widespread usage in this country, the HTW system design factors and considerations are discussed in greater detail than are those for the high pressure steam alternative.

As the result of the comparison of these alternatives, it is concluded that the high temperature water (HTW) system is the more economical and therefore is recommended for this particular installation.

PART I.

INTRODUCTION

A. Historical Review

Many years ago efforts to provide space heating were limited to heating individual rooms or small buildings. As industry and construction developed, requirements for space and process heating increased and became decentralized. These expanded requirements were first met on a widespread basis by low pressure steam heat or hot water distribution systems. The loads increased in magnitude with technological progress and the circuits increased in length. This trend was met by increasing pressures and pipe sizes. Today the point has been reached where it is necessary to investigate several alternatives whenever recommending the solution to handling a large distributed heating load.

Since World War II an additional alternative to satisfying large heating loads in this country has been the high temperature water (HTW) heating system. Since HTW has been only recently introduced in America, it will be discussed in this study in more detail than the steam system.

HTW had its genesis in 1831 when a British inventor named Angier March Perkins was granted a patent for a high pressure hot water heating system. This system commonly worked at 350 F at the furnace with the equivalent pressure of 120 psig. There was no circulation pump in the system.[15]

It was not until the 1920's that HTW applications in Germany resulted in several installations which could be used to gather experi-

ence and to be the basis for further HTW development.[10] By the start of World War II in 1939, Europe was familiar with HTW and it was utilized extensively in factory and military facilities in connection with the war effort.[15]

Since World War II HTW has been utilized for meeting some heating and process loads in this country. Today it is becoming accepted practice to consider HTW along with steam as alternatives when recommending the solution to a large heat distribution installation.

B. Terminology

It is commonly considered that high temperature water heating systems fall within the range of temperatures from 300 F on up to the critical point temperature of water with 400 F and 250 psig being the approximate economical temperature limits for most central heating plant installations. Table 1 classifies hot water heating systems.

Table 1 Classification of Hot Water Heating Systems

System	Terminology Abbreviation	Saturation Temperature Range degrees F	Saturation Pressure Range psig
Low temperature water	LTW	180 - 250	0 - 15
Medium temperature water	MTW	250 - 300	15 - 52
High temperature water	HTW	300 - 705.4	52 - 3191.5

Figure I[3] shows the range of saturation temperatures and pressures normally considered as associated with HTW. It is interesting to note that such authoritative sources as the Federal Government, the Heating, Piping and Air Conditioning Magazine, ASHAE Guide, and the Babcock and Wilcox Company do not yet agree on a definition of HTW temperature and pressure ranges. The Federal Construction Council,

Technical Report no. 37, page 34[9] presents 350 - 450 F; the HPAC Engineering Data File, page 224[12] presents 300 - 400 F; the ASHAE Guide[13] presents 250 - 430 F; while the Babcock and Wilcox Company, Bulletin G-92[3] presents 300 - 450 F.

C. Principles

1. Temperature-Pressure Relationship

Steam is generated whenever the heating process raises the water temperature to the saturation temperature for the corresponding steam and water pressure. Steam can be exported as long as its temperature remains at or above the saturation temperature corresponding to the steam pressure. Whenever water and steam are together in a container they will be at the same pressure and temperature and a change in either temperature or pressure will result in converting steam to water or water to steam.

HTW is generated whenever the heating process raises the water temperature to the 300 - 450 F range while at the same time a pressure is maintained on the water in excess of the saturation pressure corresponding to the temperature of the water. HTW can be exported as long as its pressure remains above that of the saturation pressure corresponding to its temperature. Figure I shows that as pressure is increased the saturation temperature is also increased, however, at higher pressures the increase in pressure has a diminishing effect on saturation temperature until the critical point is reached.

2. Heat Holding Capacity Ratio

HTW has a higher heat content for a given volume than does

steam at a corresponding pressure and temperature. This allows the HTW system to accumulate and store Btu's of heat within the system to a far greater extent than can the steam system. HTW at 380 F contains 37.7 times more heat in Btu/cu-ft than saturated steam at 380 F. This ratio comparison cannot be used directly, however, because for equivalent steam and HTW installations the steam supply mains would contain more volume than the HTW supply mains and the steam would probably have a lower operating pressure and average temperature than the HTW. These factors will yield a reduced heat content ratio when figured on a unit volume basis for comparison purposes between equivalently loaded installations.

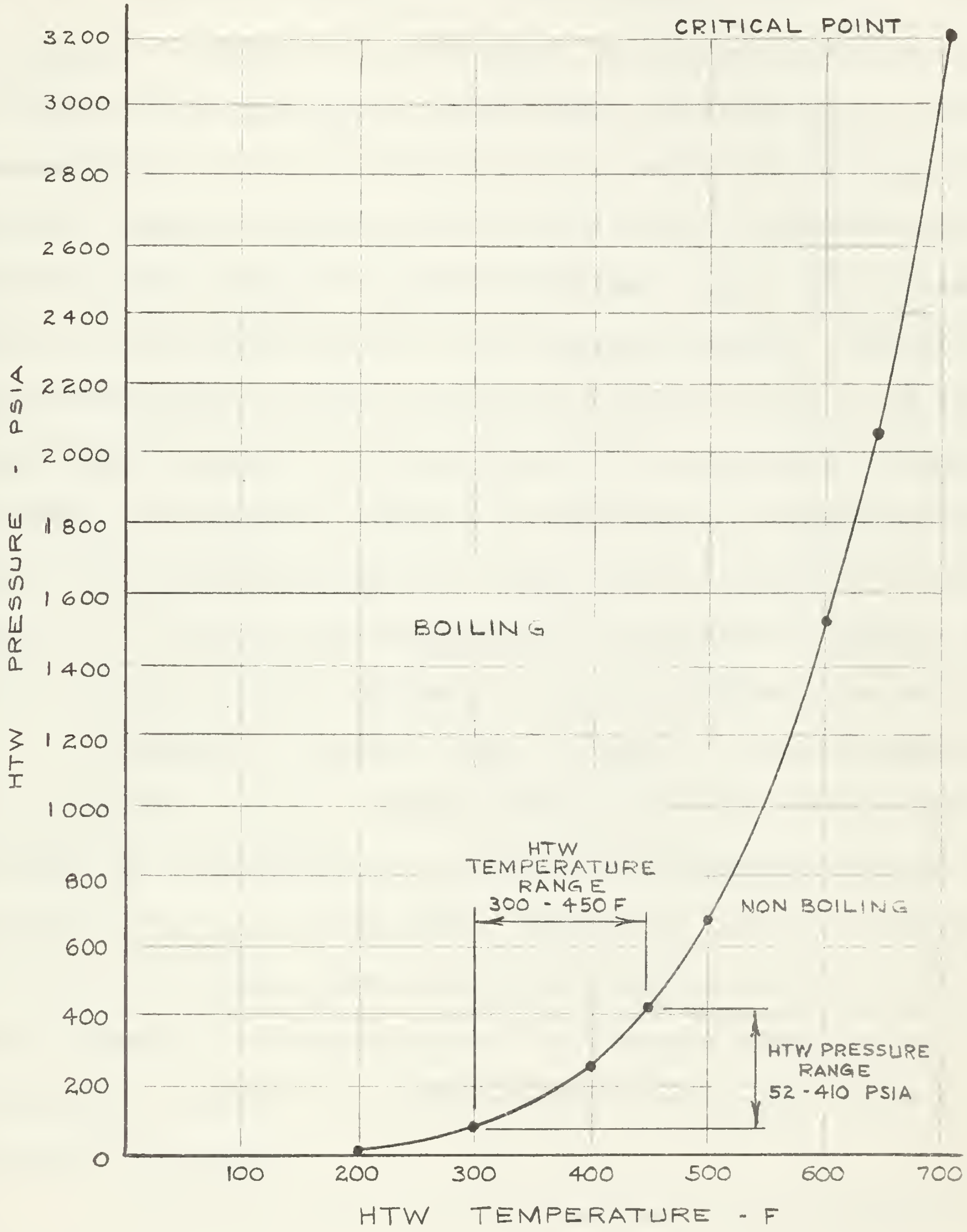


FIGURE I

HTW PRESSURE vs. SATURATION TEMPERATURE

D. Statement of the Problem

A Naval Air Station is in the planning and design stage of development. Preliminary architectural and engineering plans for the general base development are available and it is desired that a recommendation be made concerning the best method of supplying building heat, domestic hot water, and a small amount of process steam. Figure II shows the base's general development plan. The heating load is divided basically into two building groupings. Figures III and IV show building location plans for building groups I and II respectively. Group I is an operational facility occupied mainly by several air squadrons attached to the Fleet Air Command and elements of the Air Station directly supporting the squadron's missions. Group II is a training and administrative facility and provides the support for all military personnel and their dependents in the area.

The base is located in the vicinity of Portland, Maine on relatively level terrain. Contour intervals of two feet are included on Figure II and elevations of pipe stations on Figures III and IV are based on M. S. L. datum plan. The site is or will be served by rail, sea and highway. Due to the proximity and availability of electric power, all electricity will be procured commercially. Water is plentiful, however, it is from a surface source and varies in hardness with the seasons.

Construction will be of the permanent type and Table 2 lists the buildings that will result in a heat load. All domestic hot water shall be supplied at 140 F and process steam for galley cooking, the dispensary and the laundry shall be supplied at 10, 40 and 100 psig respectively.

Provision must be made for 30% future expansion in the sizing of the central heating plant and distribution piping. It is assumed that in the event of mobilization there will be very little additional construction and the mobilization requirements will be met by crowding existing facilities. This will result in no appreciable space heating load increase, however, the domestic hot water and process steam requirements will rise sharply. A diversity factor of 1.0 shall be used with all design heating and domestic hot water loads and an appropriate diversity factor shall be used for each process steam load where the calculations are based on connected equipment. The piping distribution system will be required to make numerous road crossings.

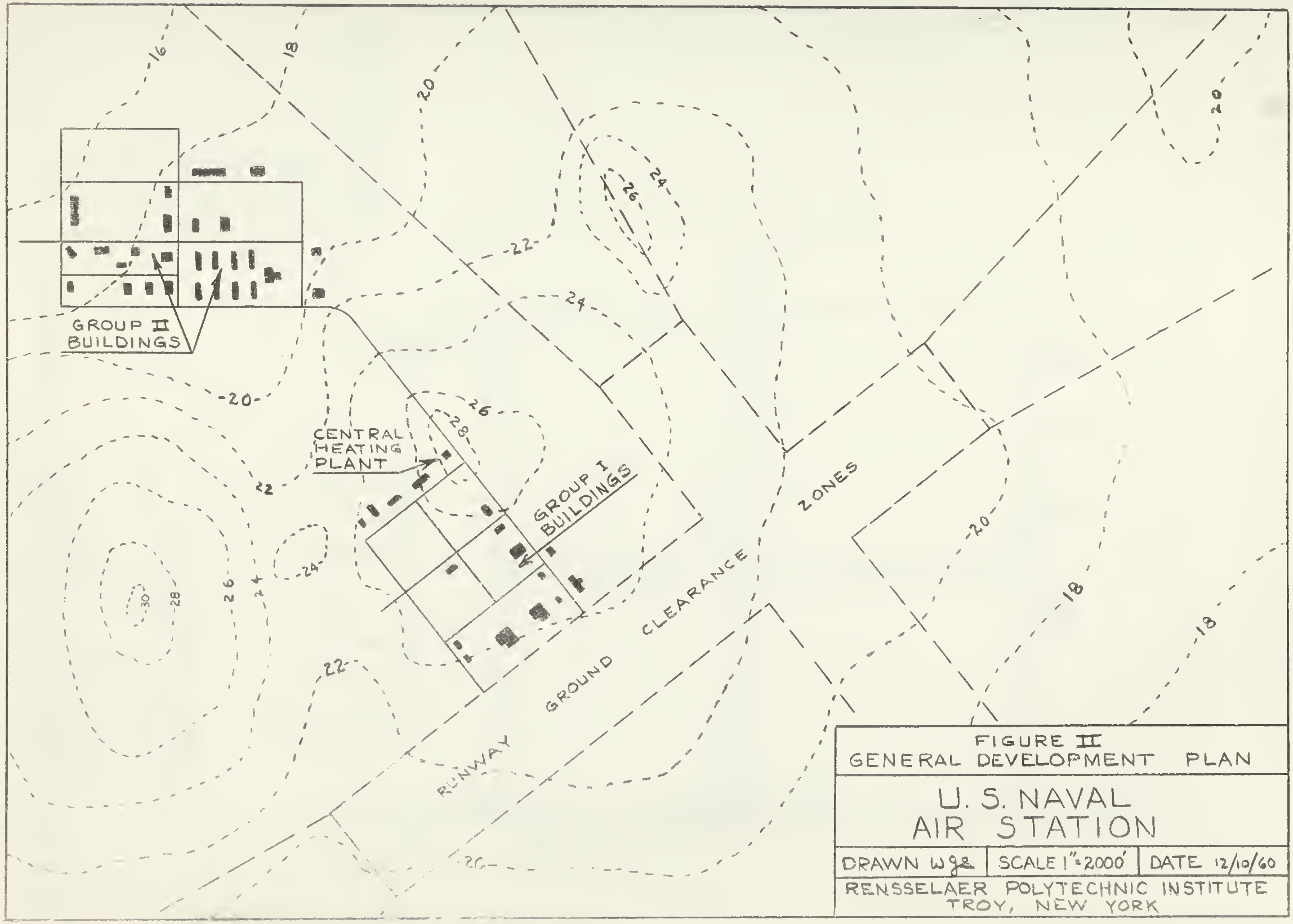
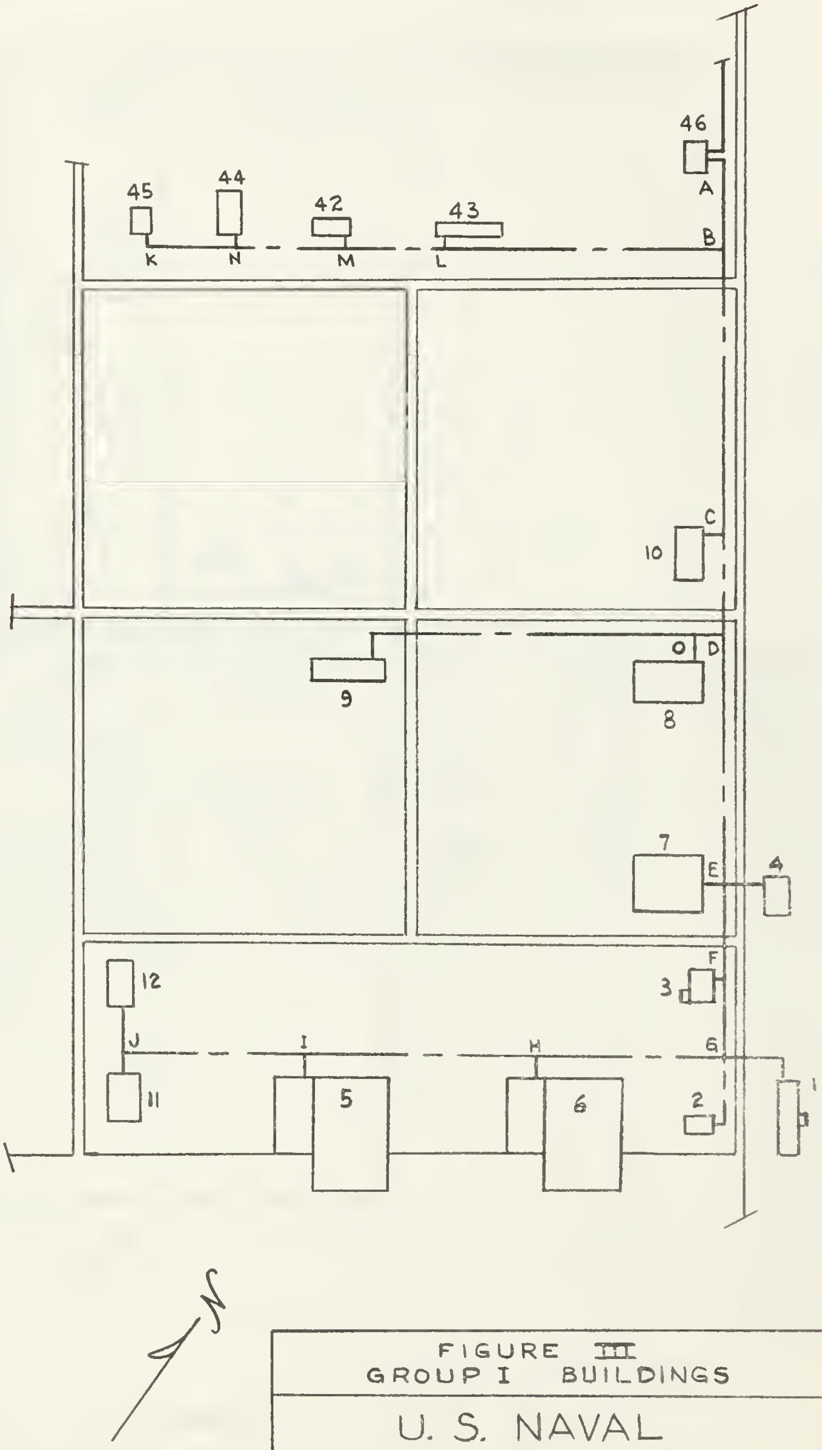


FIGURE II
GENERAL DEVELOPMENT PLAN
U. S. NAVAL AIR STATION



PIPE STATION	ELEV. ABOVE M.S.L. FT.
A	27.0
B	26.1
C	24.4
D	23.9
E	23.1
F	22.9
G	22.8
H	22.7
I	22.5
J	22.3
K	22.4
L	23.9
M	23.2
N	22.7
O	22.4

GRAPHIC SCALE

0 500

FIGURE III
GROUP I BUILDINGS

U. S. NAVAL
AIR STATION

DRAWN Wg&	SCALE 1" = 500'	DATE 12/10/60

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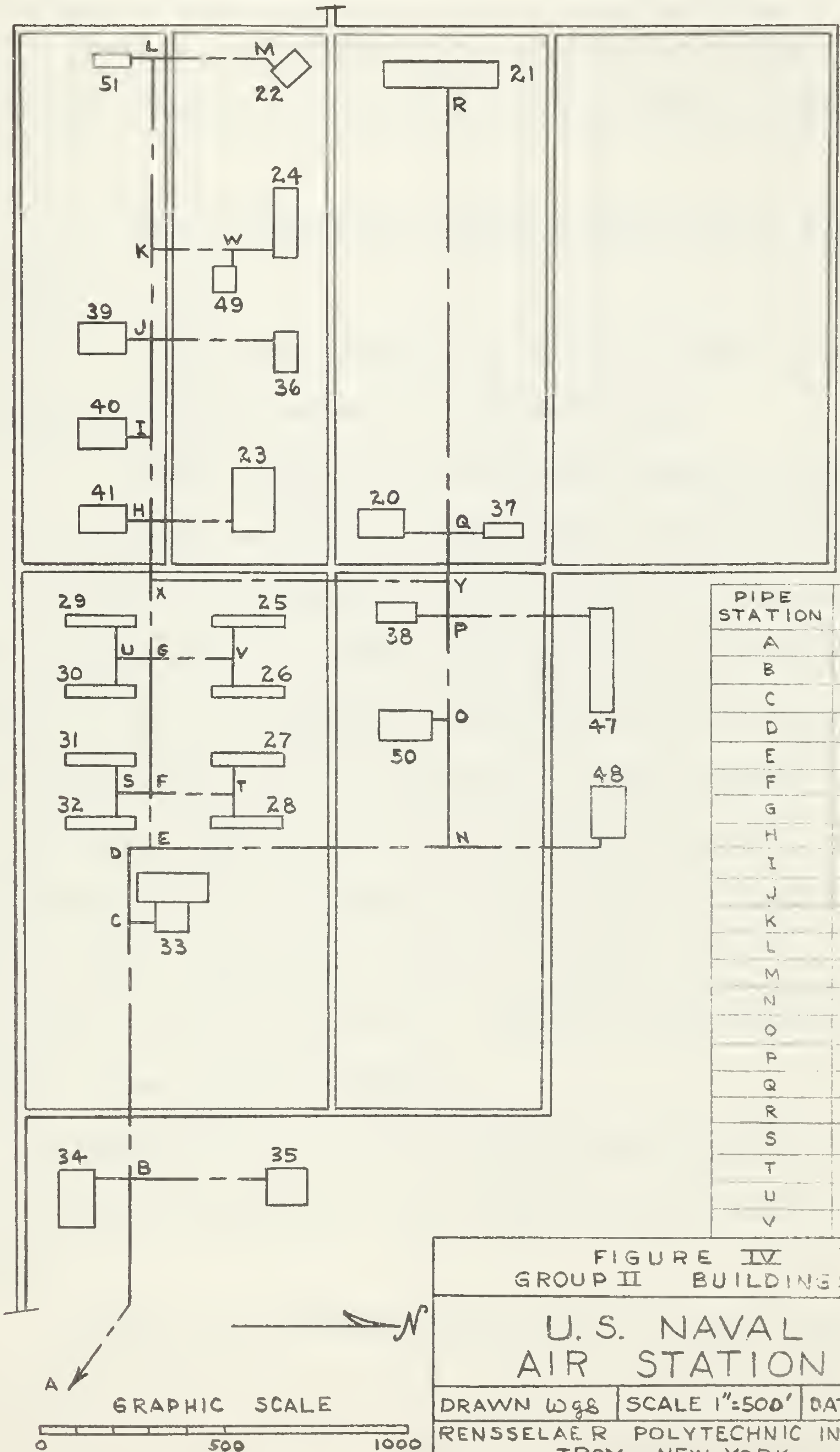

PIPE STATION	ELEV. ABOVE M.S.L. FT.
A	27.0
B	18.2
C	17.5
D	17.2
E	17.1
F	17.0
G	16.9
H	16.5
I	16.3
J	16.1
K	15.8
L	15.1
M	15.0
N	16.3
O	16.7
P	16.6
Q	16.4
R	14.4
S	16.9
T	16.9
U	16.8
V	16.8

FIGURE IV
GROUP II BUILDINGS

U. S. NAVAL
AIR STATION

DRAWN Wgs	SCALE 1"=500'	DATE 12/10/60

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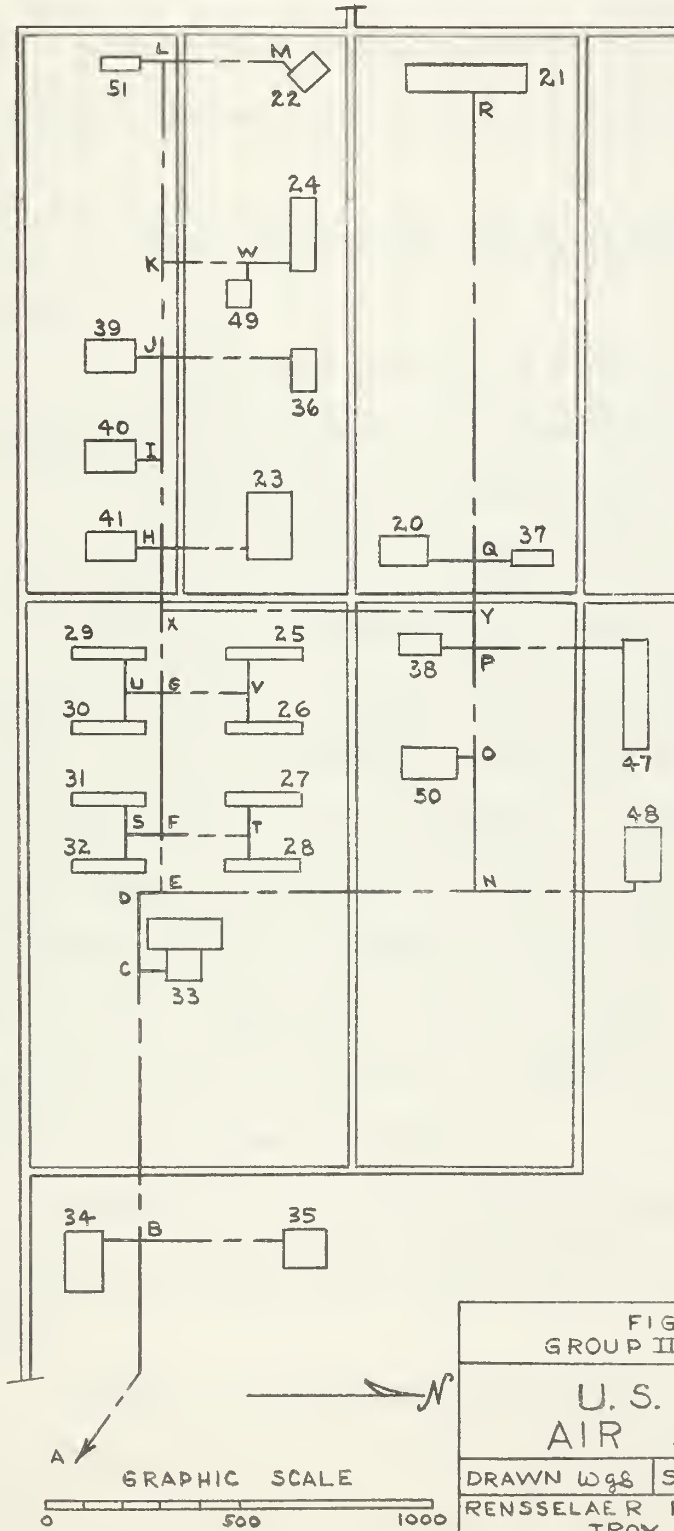

PIPE STATION	ELEV. ABOVE M.S.L. FT.
A	27.0
B	18.2
C	17.5
D	17.2
E	17.1
F	17.0
G	16.9
H	16.5
I	16.3
J	16.1
K	15.8
L	15.1
M	15.0
N	16.3
O	16.7
P	16.6
Q	16.4
R	14.4
S	16.9
T	16.9
U	16.8
V	16.8

FIGURE IV
GROUP II BUILDINGS

U. S. NAVAL
AIR STATION

DRAWN WGS	SCALE 1"=500'	DATE 12/10/60

RENSSELAER POLYTECHNIC INSTITUTE
TROY, NEW YORK

PART II.

DETERMINATION OF DESIGN HEATING LOADS

Heating load estimates are divided into four categories to facilitate tabular calculations and discussion. These categories are:

1. Heat transmission losses through walls, glass, roofs, and floors.

2. Heat losses devoted to warming outdoor air entering the building by infiltration or for ventilation.

3. Heat required to produce the domestic hot water supply.

4. Heat required to produce the process steam supply.

This is an evaluation study which is to result in a recommendation for a type of central heating plant and distribution system, therefore, it is not necessary to evaluate each building's heat losses in the detail that would be necessary if the secondary system for that individual building were actually being designed. The assumption is made that the buildings are equivalent to shells with a uniform interior temperature unless otherwise noted for a particular building and that infiltration air enters at two windward exposures and exits at two leeward exposures.

Design data for calculating heating loads is included with each building's construction and dimensional characteristics in Appendix A.

Tables for obtaining coefficients of heat transmission, U, for walls are based on a wind velocity of 15 mph. The average wind velocity for Portland, Maine for the period December to February is 10.4 mph.

Correction tables for the effect of various wind velocities on the heat transmission coefficient, U, give a very small correction for a change of wind velocity of from 15 mph to 10 mph. As an example the correction for U = .310 Btu/hr sq-ft F from 15 mph to 10 mph gives U = .305 Btu/hr sq-ft F therefore the table values of U based on 15 mph are used in this study.

Wind velocity has a material effect on the volume of air which can infiltrate a given crack. It is difficult to ascertain just what size cracks will be present in the final construction and just how well the window and door frames will remain calked after a number of years. For these reasons 15 mph is used as a conservative basis for estimating infiltration heat losses.

For calculating heat losses through walls the net wall area including doors and the net glass area based on nominal window sizes are considered as the basis for realistic estimating.

For calculating infiltration heat losses the crack method is used. To facilitate both infiltration and heat transmission losses a schedule of doors and windows with sizes, areas, coefficients and unit heat losses is included in Appendix A. The schedule letter identification is used with each building floor plan to indicate the quantities and types of windows and doors in each building exposure. Infiltration crack footage for windows is based on the maximum crack footage for any two adjacent exposures in a given building regardless of building orientation with respect to the wind. This is a valid estimating procedure because almost all of the buildings considered are practically symetrical about both their length and width

axes. Infiltration through outside doors is based on cfm per sq-ft of door under conditions of no usage and average usage unless otherwise noted for a particular building.

The design winter outdoor temperature is based on a frequency of recurrence of once in thirteen years and is taken as -9 F. The design winter indoor temperature is taken as an average value of 71 F unless otherwise noted for such semi-heated spaces as warehouses and garages. This results in an average design temperature difference of 80 F for most buildings.

Building exterior dimensions are available for planning purposes and they are used instead of the interior dimensions normally utilized for heat transmission calculations. This is a valid estimating procedure because the average building size is large and there is a very small percentage of difference between outside and inside wall dimensions.

It is estimated that ventilating air introduced to cool electronic and other heat generating equipment will be compensated for by the heat generated by the equipment. Therefore the effects of ventilation in excess of normal infiltration and the effects of heat generating equipment on the overall heat loss estimate are neglected. This procedure is only considered valid for estimating purposes in this study because the volume of space affected is extremely small in comparison to the total volume of space being heated.

Heat losses for concrete floors at or near the grade level are calculated on a per foot of exposed perimeter basis. A value of, 40 Btu/hr/ft of perimeter, is used and corresponds to a recommended edge insulation of 2 inches and an outside design temperature range of 0 to -10 F.

Heat losses for floors above crawl spaces are calculated based on the heat transmission equation using crawl space temperatures determined by a heat balance for the type of construction being considered.

The exposure factor or factor of safety to be applied to heat loss is assumed to be unity. This is justified because conservative design conditions have been used for calculating the heat losses and the final selection of equipment will be influenced in the conservative direction by mobilization and future expansion considerations.

A day's demand for domestic hot water is estimated for each building based on the type of building, the building population and the hot water required per person per day. This daily demand is multiplied by a ratio to convert it to gallons per hour of water that must be heated to meet the peak demand considering the storage capacity. This gallons per hour figure is multiplied by the relation 4 sq-ft EDR for every gallon of water per hour heated through a 100 F temperature rise.

Process steam load is estimated on the basis of totaling the consumption of steam in lbs/hr for all process equipment in a building, converting this total to Btu/hr and multiplying by the appropriate diversity factor.

The values of design heating load for each building are given in Table 2. The total of all building design heating loads plus the design condition transmission losses represent the load which the central heating plant would be required to supply to the piping distribution system to meet winter design conditions.

Individual building design heating load components are found in Table 21, Appendix A.

Table 2 List of Buildings and Their Design Heating Loads

Group I Operational Area

Building Number	Building Title	Length feet	Width feet	Stories high	Total Design Heating Load Btu/hr
1	Operations Building	200	60	2	948,060
	Control Tower	20	20	6	-
2	Fire and Crash Trucks	70	36	1	335,805
3	Parachute Building	100	60	1	323,390
	Drying Tower	16	16	3	-
4	Training Building	120	75	2	574,990
5	Maintenance Hangar	300	200	1	6,310,400
	Maintenance Shops	200	100	2	-
6	Operational Hangar	300	200	1	6,135,090
	Offices	200	100	1	-
7	Aviation Supply Warehouse	210	180	1	930,200
8	General Supply Warehouse	210	90	1	666,200
9	Flammable Supply Warehouse	180	45	1	403,420
10	Fire Station	62	90	1	479,530
11	Ordnance Shop	140	75	1	289,330
12	Paint and Dope Shop	100	60	1	227,740
42	PW Administration	130	48	2	353,040
43	PW Transportation	200	40	1	690,690
44	PW Shops	120	60	1	359,520
45	PW Storage	90	60	1	225,060
46	Heating Plant	80	60	1	309,400
	Group I buildings total design heat load				19,561,865

Table 2 List of Buildings and Their Design Heating Loads - cont'd

Group II Administrative Area

Building Number	Building Title	Length feet	Width feet	Stories High	Total Design Heating Load Btu/hr
20	Dispensary	85	60	1	562,420
21	Administration Building	320	60	2	976,870
22	All Faith Chapel	120	70	1	283,830
23	Auditorium	160	100	1	602,640
24	Navy Exchange	180	60	1	260,960
25	E.M. Barracks	221	32	3	1,847,740
26	E.M. Barracks	221	32	3	1,847,740
27	E.M. Barracks	221	32	3	1,847,740
28	E.M. Barracks	221	32	3	1,847,740
29	E.M. Barracks	221	32	3	1,847,740
30	E.M. Barracks	221	32	3	1.847,740
31	E.M. Barracks	221	32	3	1,847,740
32	E.M. Barracks	221	32	3	1,847,740
33	E.M. Mess	180	80	1	2,329,690
	Galley	100	80	1	-
34	E.M. Club	160	96	1	391,090
35	CPO Club	96	96	1	254,950
36	Laundry	100	60	1	2,822,450
37	Brig	96	32	1	187,690
38	Hobby Shop	96	48	1	220,410
39	Training Building	160	60	2	567,360
40	Training Building	160	60	2	567,360
41	Training Building	160	60	2	567,360
47	BOQ	260	48	3	1,910,850
48	Officers' Club	145	80	1	334,600
49	Commissary	100	60	1	192,360
50	Gymnasium and Lockers	160	80	1	902,750
51	Service Station	60	20	1	115,140
	Group II buildings total design heat load				28,832,700

PART III.

DESIGNS FOR HEATING SYSTEM ALTERNATIVES

The station buildings have a total design heating load of 48.4 million Btu/hr composed of the following load components:

	Btu/hr	million Btu/hr
Building heat transmission losses	17,944,200	17.9
Building heat infiltration losses	12,673,565	12.7
Heating domestic hot water	15,087,400	15.1
Process steam load	2,689,400	2.7
Total building heat load	48,394,565	48.4

During the preliminary design of the HTW heating system it was decided to provide the 100 psig laundry process steam by means of a separate package boiler unit located at the laundry. This decision was based on the comparative costs of transporting for 13,600 feet, an additional 56,000 lb water/hr capable of giving a temperature drop of 28.5 F to produce 100 psig steam vs the cost of providing 47.5 BHP package steam boiler capacity to provide laundry process steam. A 50 BHP package steam boiler was selected. The laundry will receive HTW service for domestic hot water and space heating requirements thus allowing its steam boiler to be secured when process steam is not required. Reducing the total design heating load for the HTW alternative by the 1,594,000 Btu/hr process steam load gives a total load of 46.8 million Btu/hr.

Winter and summer design heating load components for the alternative systems in million Btu/hr corrected for future expansion and calculated transmission losses are presented in Table 3.

Table 3 Design Heating Load Components

	Steam Winter Load	Steam Summer Load	HTW Winter Load	HTW Summer Load
Building heat load	48.4	17.8	46.8	16.2
Expansion allowances	14.5	5.3	14.1	4.8
Losses in distribution	6.4	6.4	4.1	4.1
Auxiliary load and losses	5.5	2.0	1.0	.3
Total heat load (million Btu/hr)	74.8	31.5	66.0	25.4

The steam boilers required at the central plant are based on winter and summer loads and standby capacity. Three boilers each of 40,000 lb/hr from and at 212 F or 38,400,000 Btu/hr capacity are recommended.

The HTW generators required at the central plant are based on the winter load times a diversity factor of .90 which takes into account the distributing system heat storage capacity of 17,825,000 Btu, the summer load and standby capacity. Three generators each of 30,000,000 Btu/hr capacity are recommended. This is equivalent to three steam boilers of 31,200 lb/hr from and at 212 F capacity.

In each case two units are required to meet winter load leaving one unit as a standby. One unit is required to meet summer load leaving one unit as a standby and the remaining unit is available for inspection and repair.

The design heating load is predominately building space heating which by its nature has a high characteristic diversity factor. Since there is need to plan for considerable future expansion, a diversity factor of unity is applied to all loads for designing pipe sizes.

Calculations for pipe sizing are detailed and tabulated in Appendix B.

Identification of piping sections for building group I, operational buildings, is detailed in figure III and building group II, administrative buildings, is detailed in figure IV of Part IV.

Pipe section XY on Figure IV is normally in the secured position and serves merely as insurance against loss of heat to certain buildings in group II by allowing manual looping of the mains and returns. Due to the characteristics of the piping layout for the group I buildings, looping is not considered practical.

A. Steam System

The steam piping distribution system is designed as a high pressure, pumped condensate system with buried piping. The central heating plant is located such that its elevation is above the elevation of all buildings which it services. It is possible to maintain a downward pitch in the direction of flow on all sections of the steam distribution system.

Pipe lines for group II buildings are designed based on a pressure drop of 50 psig from the initial pressure of 150 psig. It is required that 100 psig steam be available at the laundry for use as a process steam. This design criteria will provide the laundry with 105 psig process steam at the building utility entrance.

Pipe lines for group I buildings are designed to maintain a supply main velocity of between 7,000 and 8,000 fpm. This design results in using 6 inch steam mains which is the minimum desired size for this installation. The total pressure drop from the central heating plant to the last building serviced in group I is 71.2 psi. There is no requirement for process steam at any group I building, therefore this pressure drop is acceptable.

For purposes of this study, 150 psig operating pressure steam boilers corresponding to 365.8 F are selected. This pressure will meet all process steam needs with reasonable pipe sizing and line pressure losses while allowing the use of standard or schedule 40 piping and ASA 300 lb fittings and valves.

Steam velocity is not a critical factor in this design since the long supply mains are controlled in size by pressure loss considerations rather than velocity limitations.

B. HTW System

The HTW piping distribution system is designed as a direct return, single circuit, buried piping arrangement. This system is selected primarily for the advantages of simplicity of layout and lower initial cost but has the disadvantage of having a different pressure drop due to frictional resistance being required at each building serviced. This difference in pressure drop is compensated for by installing artificial resistances in the form of orifices and balancing cocks. The orifices will provide a means of measuring HTW flow which would not otherwise be available and will be utilized during the initial and subsequent system balancings.

The primary HTW circuit frictional resistance is calculated and used as the index for balancing all remaining circuits and branches. The primary circuit contains one building utility room HTW heating arrangement which is allowed a frictional resistance of 300 inches of water pressure drop calculated as follows:

Double seated flow rate control valve	4.0 psi
Water to water heat exchanger	5.0 psi
Utility room piping and fittings	1.5 psi
Total HTW pressure drop	10.5 psi

10.5 psi = 24.2 ft. water = 291 in. water

Assume 300 in. of 380 F water for design purposes equals 9.5 psi.

The central heating plant will contribute an additional 30 ft. of water toward the total system head loss.

HTW pipe sizes are read from curves relating heat transmitted in Btu/hr/F (equal to lbs water/hr) and frictional resistance,

(inches w.g./ft run of pipe). The curves are for 300 F water in schedule 40 steel pipe and are based on the Fanning formula. Schedule 40 pipe is utilized in this design and the average water temperature is very near 300 F, therefore no corrections are applied to the results as read directly from the curves.

Before starting to design for the primary circuit pipe sizes it is necessary to consider the following interrelated factors:

HTW generator operating pressure

Type of system pressurization

Equivalent length of pipe in primary circuit

HTW supply temperature

HTW average return temperatures

Design temperature drop for system flow calculations

Average frictional resistance

Standard pipe sizes

Total friction head or pumping head

Maximum HTW velocities

The selection of the HTW generator operating pressure will allow a determination of system temperatures, pipe sizes and head losses. For purposes of this study the commercially standard generator operating pressures of 200 and 250 psig will be examined with respect to their effect on the design before one of them is selected. The primary circuit has 16,397 equivalent ft. of straight pipe with approximately one-half of this amount, or 8,153 equiv. ft., being in the main pipe section AB leading to and from the central heating plant. An examination of the relation between pipe size and head

loss for this section of pipe will be representative of the pattern for the system design. To facilitate this examination it is first necessary to develop the relationship between pressure and temperature for the HTW system at each operative pressure under consideration.

It is considered that the maximum return temperature of the HTW at the heating plant required to maintain adequate system response during periods of low loading will be 20 F less than the HTW supply temperature. A 200 psig operating pressure gives the relationships in Table 4.

Table 4 200 psig HTW relationships

HTW supply temp. (F)	350	360	370	380
Pressure corresponding to the supply sat. temp. (psig)	119.9	138.3	158.7	181.1
Gas pressurization (psig)	80.1	61.7	41.3	18.9
Maximum HTW return temp. (F)	330	340	350	360
Pressure corresponding to the max. return sat. temp. (psig)	88.4	103.3	119.9	138.3
Pressure drop available for friction head loss (psig)	111.6	96.7	80.1	61.7
Equivalent head available for losses (ft. of water)	257	223	185	142
Equivalent head devoted to plant losses (ft. of water)	30	30	30	30
Equivalent head available for primary circuit losses (ft. of water)	227	193	155	112

A 250 psig operating pressure gives the relationships in Table 5.

Table 5 250 psig HTW Relationships

HTW supply temp. (F)	370	380	390	400
Pressure corresponding to the supply sat. temp. (psig)	158.7	181.1	205.7	232.6
Gas pressurization (psig)	91.3	68.9	44.3	17.4
Maximum HTW return temp. (F)	350	360	370	380
Pressure corresponding to the max. return sat. temp. (psig)	119.9	138.3	158.7	181.1
Pressure drop available for friction head loss (psig)	130.1	111.7	91.3	68.9
Equivalent head available for losses (ft. of water)	300	257	210	159
Equivalent head devoted to plant losses (ft. of water)	30	30	30	30
Equivalent head available for primary circuit losses (ft. of water)	270	227	180	129

Considering the relationship between pipe size and head loss and using the main section AB to group II buildings as being conservatively representative of the system for different design temperature drops gives the results in Tables 6 and 7.

Table 6* Head Loss by Pipe Sizes

Pipe Size Section AB in.	Average Frictional Resistance in. of water/ft	Distribution Piping Total Head Loss in. of water	Primary Circuit Head Loss in. of water	Primary Circuit Head Loss ft. of water
9	.023	377	677	56
8	.041	679	972	81
7	.082	1,344	1,644	137
6	.180	2,950	3,250	271

*Table 6 is based on a design temperature drop of 150 F and a HTW rate of 260,000 lbs water/hr.

Table 7* Head Loss by Pipe Sizes

Pipe Size Section AB in.	Average Frictional Resistance in. of water/ft	Distribution Piping Total Head Loss in. of water	Primary Circuit Head Loss in. of water	Primary Circuit Head Loss ft. of water
9	.019	312	612	51
8	.033	541	841	70
7	.066	1,082	1,382	115
6	.143	2,342	2,642	220

It can be noted that the heads available for primary circuit losses for both operating pressures of 200 and 250 psig all fall between a 6 and 8 inch pipe straddling the 7 inch pipe. Since the 7 inch pipe is a non-standard size it would be convenient to use either of the standard sizes of 6 or 8 inches. Economies dictate utilizing the smallest possible pipe sizes provided the pumping head is maintained within balance and certain velocities are not exceeded. Before a pipe size and export temperature can be selected for design it is necessary to determine the minimum return HTW temperature which in effect will control the design temperature drop.

The minimum return HTW temperature is selected as 220 F. This temperature will be high enough to control flue gas condensation in the economizer and thermal shock in the generator but low enough to result in a desirable design temperature difference.

A 400 F supply temperature at 250 psig would result in a design temperature drop of 180 F and a prospective primary circuit head loss of 190 ft. of water for a 6 inch pipe in section AB. Since there are only 129 ft of water available it would not be possible to design for these conditions even by reducing the average frictional

*Table 7 is based on a design temperature drop of 170 F and a HTW rate of 229,000 lbs water/hr.

resistance for the remainder of the primary circuit. This can be shown by:

Available head for losses	129 (ft of water)
Head for utility rooms	25 (ft of water)
Available head for piping	104 (ft of water)
Head for section AB alone	82 (ft of water)
Head remaining for rest of the primary circuit	22 (ft of water)

Whereby the average frictional resistance for the remaining 8,244 equivalent ft. of piping would have to equal .032 in. water/ft of pipe. This is not practical with the loadings involved beyond section AB.

A 390 F supply temperature at 250 psig would result in a design temperature drop of 170 F and a primary circuit head loss of 220 ft of water for a 6 inch pipe in Section AB. There are 180 ft. of water available for head loss and it appears that this combination will give the smallest pipe size and largest design temperature drop possible within prescribed pressure limitations by merely adjusting the average frictional resistance for the remainder of the primary circuit.

Available head for losses	180 (ft of water)
Head for utility rooms	25 (ft of water)
Available head for piping	155 (ft of water)
Head for section AB alone	98 (ft of water)
Head remaining for rest of the primary circuit	57 (ft of water)

Whereby the average frictional resistance for the remaining 8,244 equivalent ft of piping would have to equal .083 in. of water/ft of pipe. This combination appears to be realistic and is selected for performing the design calculations.

Table 8 shows the portioning of total pump head when utilizing 390 F supply HTW, 170 F design temperature drop, and 250 psig operating pressure.

Table 8 Portioning of Total Pump Head

System Component	Head Required	Percent of Total Hours
Utility room HTW side	25 (ft of water)	12%
Central heating plant	30 (ft of water)	14%
Distribution piping	155 (ft of water)	74%
	210 (ft of water)	100%

A normal range for distribution piping head loss would be from 50 to 80% of the system head loss with the former being for shorter pipe runs and the latter for longer pipe runs.

A maximum water velocity of 4.0 fps is recommended where noise might pose a problem. Since this distribution system is buried and in general is remote from buildings, the velocities are limited in accordance with Table 9.

Table 9 Water Velocities for HTW Piping[17]

pipe size (inches)	$2\frac{1}{2}$	3	4	5	6	8	10	12
velocity (fps)	5	$5\frac{1}{2}$	7	8	9	10	11	12

The HTW system will be pressurized by means of a mechanical system utilizing nitrogen gas and connected to the return distribution main just ahead of the system circulating pumps. The nitrogen tank does not have any system water flowing through it when the system is in temperature equilibrium. There is a water seal in the lower

quarter of the drum which raises and lowers as the return water expands and contracts. This pressure drum and its pressure relief overflow tank have two functions which are providing adequate system pressure to assure that HTW is not reduced in pressure sufficiently to be able to flash to steam anywhere in the system and to provide a storage reservoir for system water that expands out of the circulating system as the return water temperature increases.

Since HTW pressure and saturated liquid temperature are interdependent at any point in the HTW system, the problem of fixing temperature drops and system pressurization must be considered together.

For purposes of this study, 250 psig operating pressure HTW generators providing 390 F HTW are selected. Thus the nitrogen pressurization will provide the necessary pressure differential of 44.3 psi which when added to the pressure corresponding to the saturated temperature of the export water will maintain system and boiler operating pressures.

It is desirable to have a maximum temperature drop over which the HTW may operate. This will result in a minimum HTW flow rate and the smallest pipe sizes. It is good practice to have a margin of safety in terms of pressure on the return line at the maximum return temperature of 370 F. Therefore the distribution system selected must not exceed 210 ft of water head loss but must be slightly below this figure to assure safe design.

The actual head loss in the entire system's primary circuit plus the central heating plant equipment is calculated to be 196 ft of water under design conditions. This results in a safety

factor of 14 ft of water or 6 psi above the saturation pressure devoted to preventing the maximum temperature HTW in the return line from flashing into steam at the system return header. It should be noted that the design conditions for which the prevention of flashing have been taken are the maximum HTW return temperature at very light load and the maximum flow conditions at design full load. These conditions should not occur simultaneously and this in itself is the greatest factor of safety with respect to return water flashing.

All piping is designed for the maximum pressure within the system. Standard and schedule 40 pipe have equal dimensions for all pipe sizes up to 10 inches and a check on stress for 250 psig operating pressure reveals that the piping design is well within code limitations.

ASTM-A135 electric resistance welded steel pipe has the following stress limitations:

Grade	Minimum Ultimate Tensil Strength	Values of Stress for the -20 F to 650 F Temp. Range
A	48,000 psi	10,200 psi
B	60,000 psi	12,750 psi

Check stress by Barlow's Formula based on the outside pipe diameter.

6" pipe, 250 psig, standard, schedule 40

$$S = \frac{PD}{2t} = \frac{(250 \text{ psi})(6.625 \text{ in.})}{2(.280 \text{ in.})} = 2,960 \text{ psi}$$

2" pipe, 250 psig, standard, schedule 40

$$S = \frac{PD}{2t} = \frac{250(2.375)}{2(.154)} = 1,930 \text{ psi}$$

P = internal pressure (psig)

D = outside diameter (in.)

t = wall thickness (in.)

s = unit stress (psi)

A minimum water flow by-pass line is located in the central heating plant just after the circulating pumps to assure the minimum water flow required by the forced circulation HTW generators at times when the system flow is reduced below the minimum HTW generator flow rate.

This minimum water flow by-pass line can also be used during system warmup periods to maintain feedwater temperature above the dew point of sulphur bearing combustion gases and above the temperature which would result in undue thermal stress due to temperature difference. With the return water temperature of 220 F, no difficulty will be encountered from thermal stresses in the boiler due to a water temperature difference of 170 F. This is conservative since a water temperature rise of 200 F or larger is widely used and considered good practice.[14] This is primarily due to the forced recirculation pumping feature which delivers water at a velocity of 6 to 8 fps through internal generator tubes. In addition, generators contain an economizer section in which the return water temperature is increased by the flue gases before reaching the generator tube walls.

A minimum water flow by-pass valve is located at the end of each circuit to assure that sufficient water flow rates are maintained in each circuit to maintain system temperature at no or low loading conditions.

Pumping capacity is determined from HTW flow rate and water temperature at the pumps. The flow rate is based on the heat carrying capacity of water and the temperature difference which the water is able to give up in circuiting the distribution system. Therefore, the total heat load divided by the design temperature drop provides the flow rate of HTW directly in pounds per hour since the specific heat of water is considered as unity. The piping system as designed establishes the pump head required to exactly balance the flow resistance.

Pipe sizing and pump selection are integrated so that the final design will include both standard pipe and pump sizes. After pipe sizing was completed, an accurate determination of flow resistance was made.

Pump selection is based on a flow rate of 382,000 lb water/hr. Since the pumps are placed in the return line just prior to the HTW generators to assure adequate forced water circulation for these generators, the pumps actually handle HTW at the return header temperature of 220 F at full load conditions. Therefore, each pump will handle 800 gpm of 220 F HTW against a head of 196 ft of water at design operation.

Two pumps are selected to be installed in parallel so that either pump will deliver the 800 gpm required under the design conditions. Control of flow rate is obtained by varying the pump speed and operating with incremental changes of HTW generator return water as dictated by load conditions and by pass valve settings.

Continuous pumping is required to maintain desired system supply temperatures at all points in the distribution system and minimum HTW generator flow even under low load conditions. There-

fore, it is necessary to consider the relationship between pump flow rate, water temperature and resistance balance point for the entire range of flow rates reqired when specifying pumps.

A pump with a relatively flat curve characteristic is preferred since it provides the least system head change and greatest system flow change as individual building control valves close and influence the system.

The mechanical system pressurization connection is near the pump suction lines and assures sufficient NPSH to preclude excessive pump cavitation.

Pump suction and discharge lines are sized not to exceed the following velocities given in Table 10.[20]

Table 10 Pump Piping Sizes

Pump Suction Lines

Velocity fps	Pipe Size in.
2-3	all

Pump Discharge Lines

Velocity fps	Pipe Size in.
4-6	up to 2
5-8	$2\frac{1}{2}$ to 6
6-10	6 and up

PART IV.

COMPARISON OF ALTERNATIVES

The two alternatives considered in this study are compared on a design, operation, maintenance, and cost basis so that one of them may be selected as the recommended solution.

A. Design Comparison

A comparison of alternatives on a design basis is presented in Table 11.

Table 11 Comparison of Alternatives on a Design Basis

Item	Steam Alternative	HTW Alternative
Type of system	pumped condensate, direct return	Direct return, single circuit
Operating pressure	150 psig	250 psig
Operating temperature	365.8 F	390 F
Return temperature	180 F condensate	220 F
Design drop	50 psig major circuit	170 F
Circulation pump head	-	196 ft
Circulation pump capacity	-	800 gpm
Largest main sizes	10 in.	6 in.
Distribution piping	47,894 ft.	47,894 ft.
Volume of supply piping	3,887 cu-ft	2,135 cu-ft
Heat storage capacity	1,247,000 Btu	17,825,000 Btu
Diversity factor for boiler sizing	1.0	.90
Boiler size (3 each) from and at 212 F	40,000 lb/hr	30,000 MBtu/hr
Design boiler loading from and at 212 F	77,300 lb/hr	66,000 MBtu/hr
Annual boiler loading	175.8×10^9 Btu	141.5×10^9 Btu

It is calculated that at design conditions the steam generation of two boilers will provide the heat storage capacity of the supply piping in 58.5 seconds. Two HTW generators will provide the heat storage capacity of the HTW supply piping in 17 minutes and 50 seconds. This time difference stems from the inherent operating characteristics of the two systems.

Steam must be generated simultaneously with load demand. In effect steam can not be stored for use in a distribution system because it relies on a change of phase for its ability to meet load demands. HTW does not change phase and can effectively store heat in the distribution system. This stored heat is used to meet sudden and peak load demands and has the direct effect of moderating or evening load demands at the HTW generators. For the systems of this study there is a ratio of HTW to steam heat storage in the supply piping of 14.3 to 1. Since the systems are of unequal volume the ratio of HTW to steam heat storage for one cubic foot of inside pipe volume at design conditions is 26.1 to 1. In practice it has been found that this heat storage capability of the HTW system results in allowing for a HTW generator sizing diversity factor of as low as .80 to be used. A conservative diversity factor of .90 is used in this study.

To facilitate piping design, heat losses for the steam distribution system were assumed to be 15 percent of supply heat and were actually calculated to be 9.25 percent. Heat losses for the HTW distribution system were assumed to be 10 percent of supply heat and were actually calculated to be 6.35 percent.

It should be noted that the ratios of 15% to 10% and 9.25% to 6.35% are 1.50 and 1.46 respectively, or very nearly equal. This indicates that the effect of the assumed loss for design purposes for both alternative systems are also nearly equal. The pipe sizes were calculated using the assumed percentages of heat losses but the boiler and generator capacities were determined by using the actual calculated heat losses. The pipe sizes were not rechecked utilizing actual calculated heat losses since the effect is not appreciable and will result in slightly conservative pipe sizing for both alternatives. This procedure can be thought of as resulting in an increase of the allowance for future expansion by approximately 3 percent to a new figure of 33 percent. This is acceptable for purposes of this study.

Figures V, VI, VII, and VIII are schematics of piping and equipment arrangements for both the steam and HTW alternatives.

B. Operation and Maintenance Comparison

A comparison of the alternatives for main points of operation and maintenance is presented in Table 12.

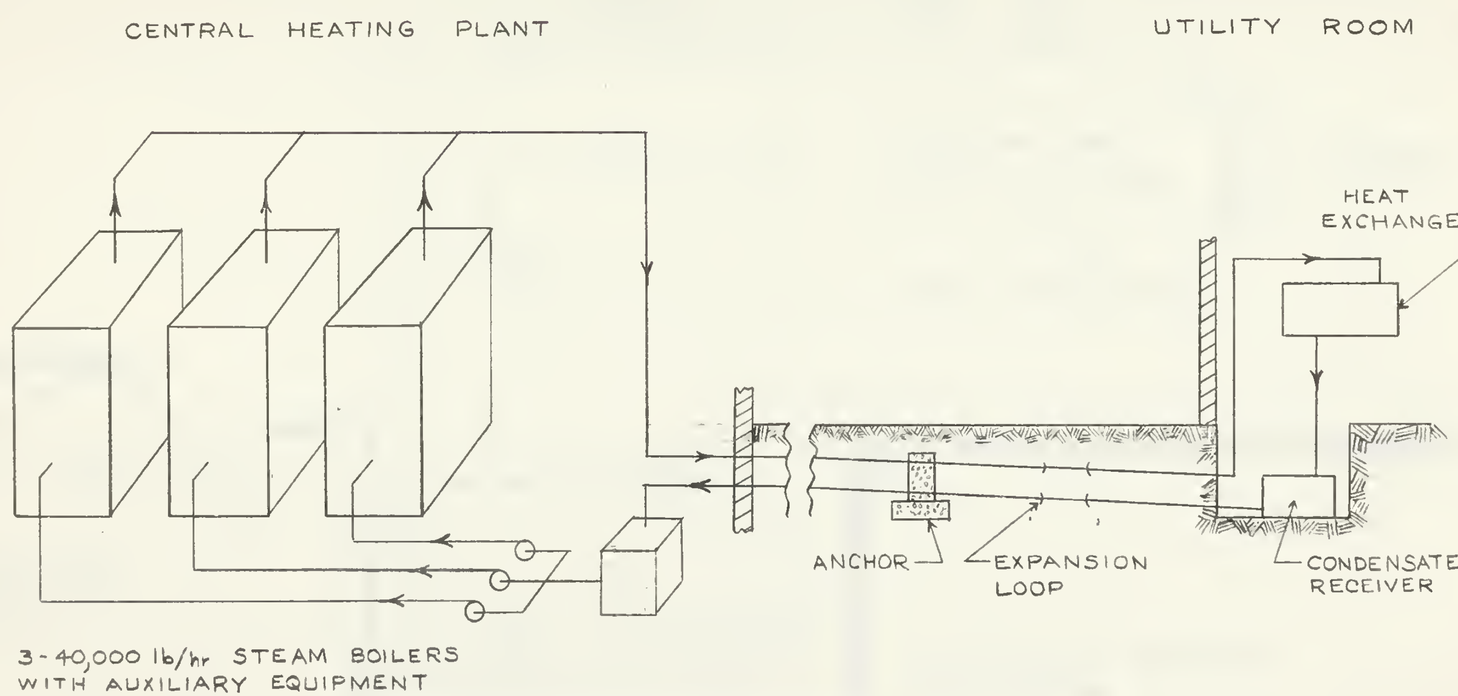

FIGURE V

SCHEMATIC ARRANGEMENT OF STEAM EQUIPMENT

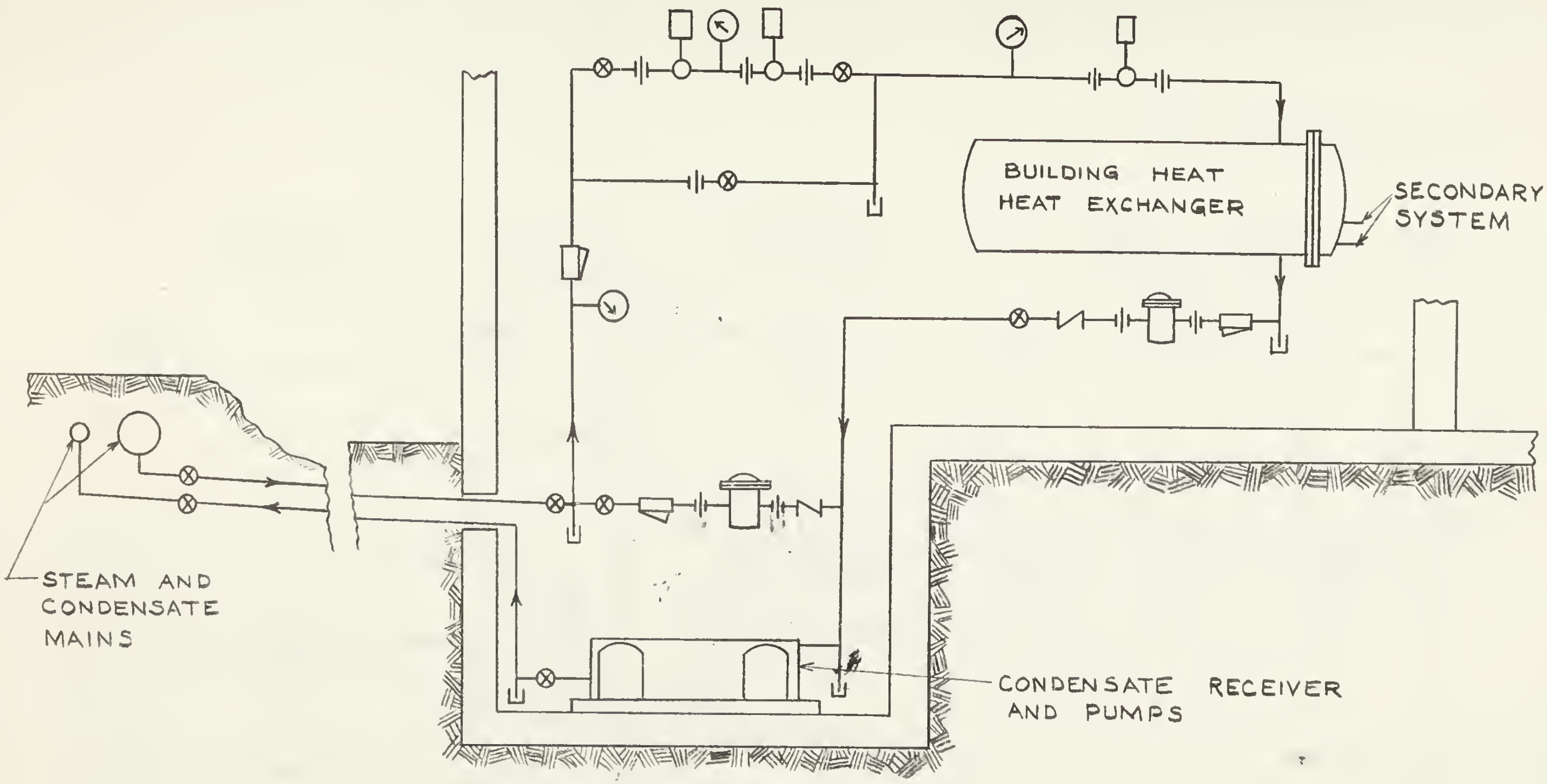

FIGURE VI

SCHEMATIC - TYPICAL STEAM BUILDING UTILITY ROOM

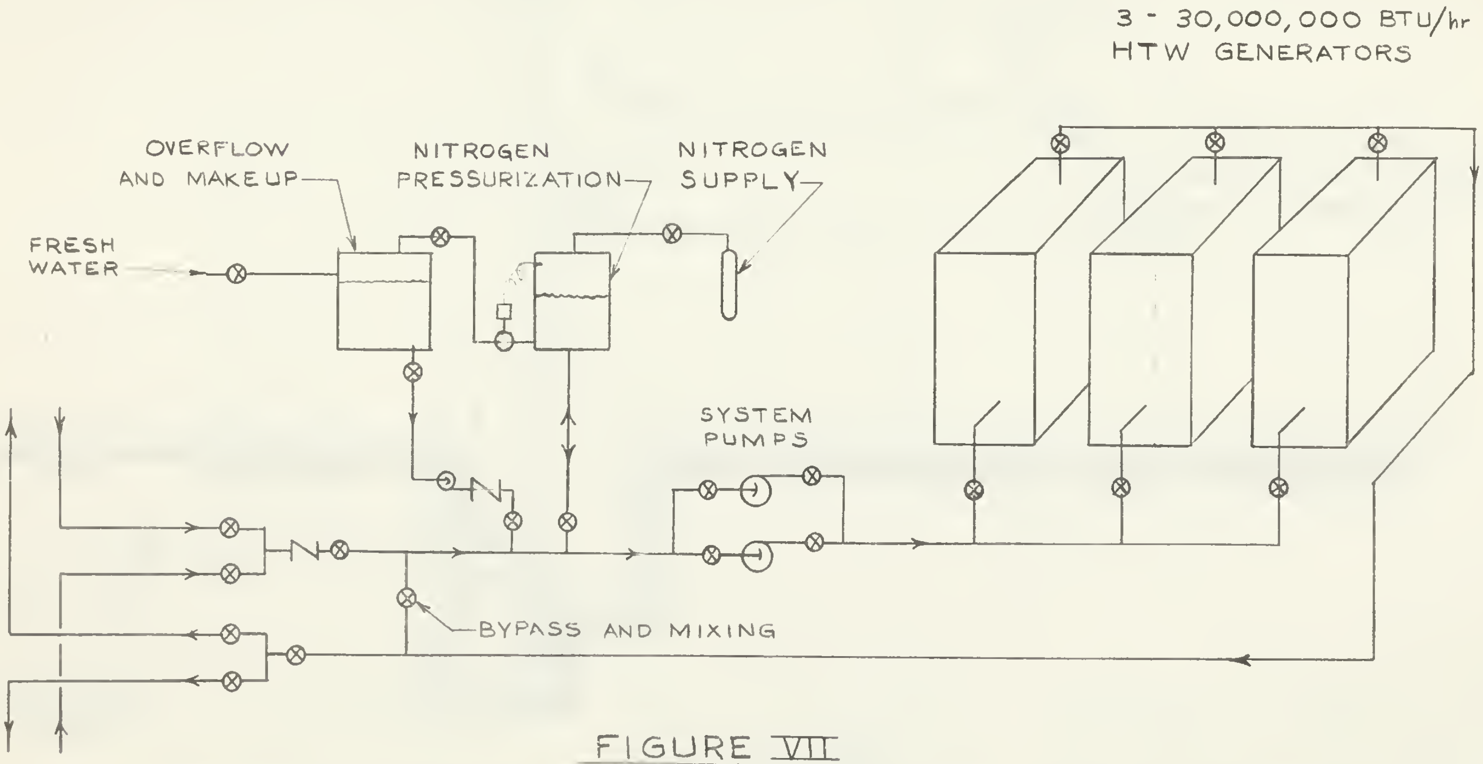

FIGURE VII

SCHEMATIC ARRANGEMENT OF HTW GENERATION EQUIPMENT

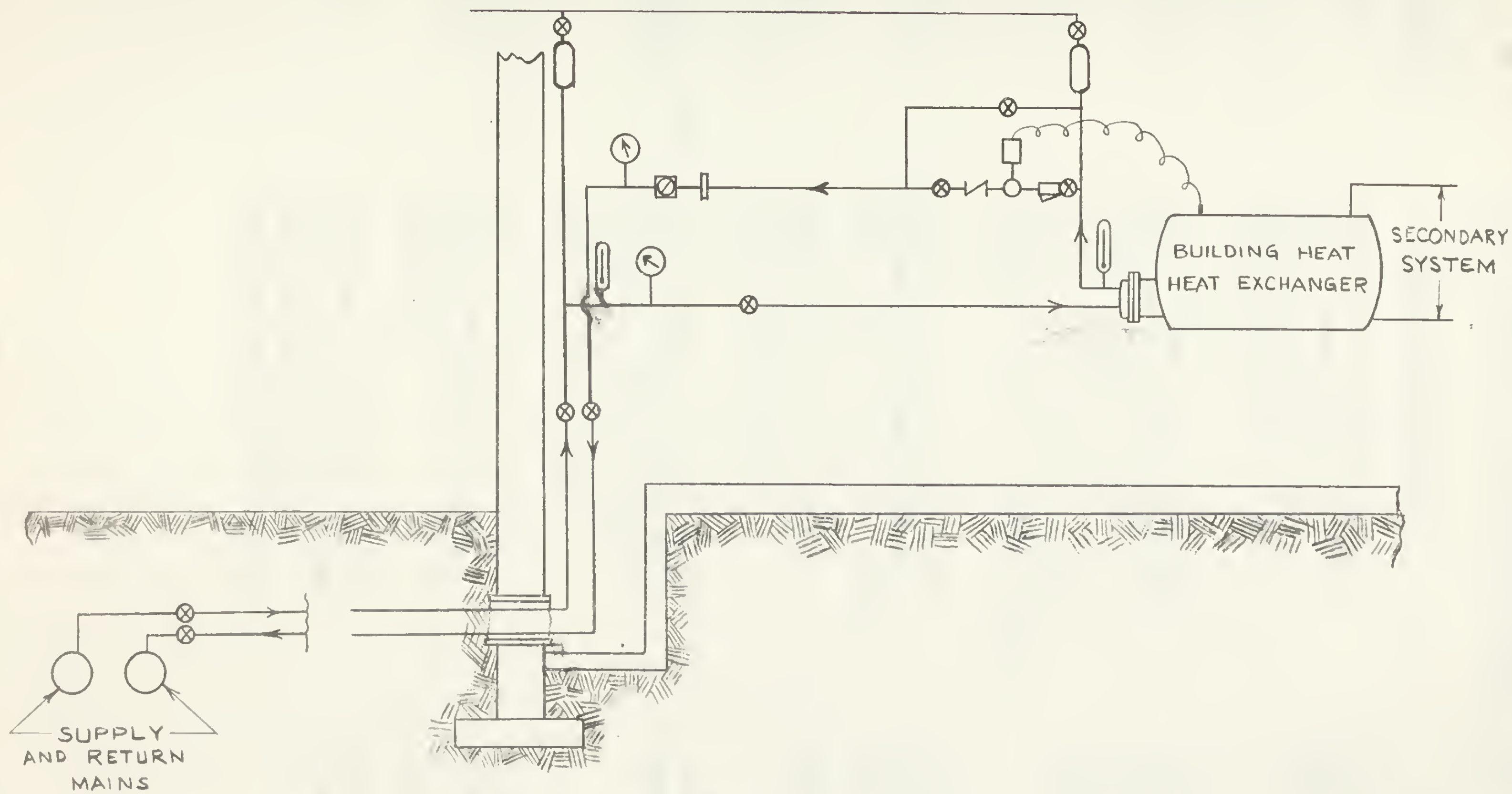

FIGURE VIII

SCHEMATIC - TYPICAL HTW BUILDING UTILITY ROOM

Table 12 Comparison of Alternatives on an Operation and Maintenance Basis

Operation Item	Steam Alternative	HTW Alternative
Pumps	Individual pumps handle small quantities of condensate intermittently. Feedwater pumps operate continuously.	A single circulating pump operates continuously.
Boilers	System heat load demands are immediately reflected at the boiler. Over a period of time this uneven firing with higher stack losses results in efficiency losses.	System heat load demands are initially met by heat stored in the distribution system. Boilers operate smoothly.
Blowdown	Periodic boiler blowdown causes increased boiler heat output and fuel usage.	Blowdown is negligible in the closed loop system.
Water Treatment	Required for all makeup water, 4,813 lb/hr at design operation	Very small requirement.
Flashing and Leakage	Flash losses at all traps and at central plant and leakage losses at valve stems cause increased boiler heat out put.	Flashing does not occur. Leakage is negligible.
Transmission Losses	Losses exterior to the plant are 9.25 percent of supply heat at design operation.	Losses exterior to the plant are 6.35 percent of supply heat at design operation.
Fuel	Requires more fuel mainly due to additional losses and immediate boiler response characteristic.	Requires 15.4 percent less fuel annually.

Maintenance Item	Steam Alternative	HTW Alternative
Boilers	Maintenance to maintain efficiency due to scale formations in boiler tubes.	Negligible scale formations.
Pumps	Many smaller pumps scattered over a wide area.	Two large pumps in the central plant.
Distribution System	Traps, pressure reducing stations and valves require maintenance. Condensate piping subject to corrosion and ultimate renewal before steam piping.	No traps or pressure reducing valves in the system. Negligible corrosion in all piping characteristic of a close system.

C. Annual Cost Comparison

A comparison of the alternatives on an annual basis of cost to own and operate is presented in Table 13. Amortization is based on 20 year retirement at $4\frac{1}{2}\%$ compound interest and equals the capital investment at present worth times the factor .07688. The salvage value of the investment is considered to be equal to the cost of removing the equipment from the site. The effect of inflation is neglected.

Table 13 Summary of Fixed and Operating Charges

Item	Steam	HTW
Central heating plant	$ 384,350	$ 388,550
Distribution system	515,390	466,023
Building utility rooms	416,250	351,500
Laundry boiler.	-	10,300
Total	$1,315,990	$1,216,373

Annual Operating Charges

Item	Steam	HTW
Fuel	99,150	$ 83,900
Electricity.	2,620	5,240
Water.	1,013	18
Operating labor.	60,000	60,000
Operating materials.	3,000	2,000
Maintenance labor, plant	12,000	12,000
Maintenance labor, system.	24,000	12,000
Maintenance material, plant.	1,200	1,200
Maintenance material, system	2,400	1,200
Supervision and clerical	12,000	12,000
Laundry boiler operation	-	8,000
Total annual operating cost	$ 217,383	$ 197,558

Annual Cost to Own and Operate

Item	Steam	HTW
Amortization	$ 101,100	$ 93,500
Operation.	217,400	197,600
Annual cost to owner	$ 318,500	$ 291,100

PART V.

CONCLUSIONS

Based on the economical comparison of the total cost to own and operate the alternative central heating systems, it is recommended that the HTW system alternative be selected for final design.

PART VI.

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PART VII.

APPENDIXES

APPENDIX A

Calculations for Design Heating Loads

I. Design Data for Winter Conditions

A. Inside design temperatures

1. Average . . . . 71 F

2. Maintenance and operational hangers . . . . 60 F

3. Warehouses and storage building . . . . 60 F

4. Paint shop . . . . 80 F

5. Dispensary and locker rooms . . . . 75 F

6. Shops, garages, and gymnasium . . . 65 F

7. Underfloor crawl spaces

a. Floor U = .57 . . . . 53 F

b. Floor U = .29 . . . . 41 F

B. Outside design temperature . . . . -9 F

C. Design wind velocity. . . . . 15 mph

D. Domestic hot water temperature . . . . . 140 F

E. Supply water temperature. . . . . 40 F

F. Coefficients of heat transmission, U, (Btu/hr sq-ft F); infiltration values for windows in (cfm/ft crack); and infiltration values for doors in (cfm/sq-ft door) are taken from the Heating, Ventilating and Air Conditioning Guide, 1959, and Modern Air Condition-

ing, Heating and Ventilating, 1959, by Carrier, Cherne, Grant and Roberts.

II. Design Heat Load Estimating Relationships

A. Heat transmission through walls, roofs, glass and floor slabs above crawl spaces

Heat loss in (Btu/hr) = (U)(Area)(design temp. diff.)

B. Heat transmission through floor slabs directly on the ground and near ground level

Heat loss in (Btu/hr) = (40 Btu/hr/ft-perimeter) (feet of exposed perimeter)

C. Heat loss due to infiltration air

Heat loss in (Btu/hr) = 1.08 (cfm/ft of crack) (crack footage)(design temp. diff.)

D. Heat load due to heating domestic hot water

Heat load in (Btu/hr) = (Gallons HW/day/building) (heating capacity ratio)(4 sq-ft EDR/100 F temp rise)(240 Btu/sq-ft EDR)

E. Heat load due to steam processes

Heat load in (Btu/hr) = (steam requirement in lb/hr) (Enthalpy saturated steam in Btu/lb - Enthalpy fresh water in Btu/lb)(diversity factor)

F. Determination of crawl space temperature by heat balance

1. Building Number 1* floor type F2, U = .57 Btu/hr sq-ft F

(Heat gain through floor) = (heat lost through walls below ground) + (heat lost through walls above ground) + (heat lost to ground) + (heat lost to air changes).

(12,000 sq-ft)(.57 Btu/hr sq-ft F)(71 F - T) = (520 ft perimeter)(1 ft height)(4.0 Btu/hr sq-ft) + (520 ft perimeter)(2 ft height)(.29 Btu/hr sq-ft F)(T - (-9F)) + (12,000 sq-ft ground)(2.0 Btu/hr sq-ft) + (1.08)(2 air changes/hr)(36,000 cu-ft/air change)(1 hr/60 min)(T - (-9 F)).

solving T = 53 F

2. Building Number 39* floor type F3, U = .29 Btu/hr sq-ft F

(9,600 sq-ft)(.29)(71 F - T) = (440 ft perimeter)(1 ft height)(4.0 Btu/hr sq-ft) + (440 ft perimeter)(2 ft height)(.25 Btu/hr sq-ft F)(T - (-9 F)) + (9,600 sq ft ground)(20 Btu/hr sq-ft) + 1.08 (2 air changes/hr)(28,800 cu-ft/air change)(1 hr/60 min)(T - (-9 F)).

solving T = 41 F

III. Construction Schedules

Tables 14 and 15 are door and windowschedules giving the unit infiltration heat losses in Btu/hr for standard doors and windows based on a design temperature difference of 80 F. These values are used to summarize each building's infiltration heat losses. Wherever the design temperature difference differs from 80 F, these values are multiplied by the ratio of (actual design temperature difference/80 F).

* These buildings are typical for two types of floors with crawl spaces and the temperatures calculated will be utilized for calculating floor heat losses of other buildings with similar characteristics.

Tables 16, 17 and 18 are wall, roof, and floor construction schedules which include the appropriate value of the heat transmission coefficient for each type of construction. The wall, roof, and floor construction schedule designators are used in the following floor plan figures to denote individual building construction features.

Table 14 Door Construction Schedule

Schedule Letter	Dimensions (feet)	Area (sq. ft.)	Infiltration cfm/sq. ft.	Infiltration with 80 F temp. dif. (Btu/hr.)
A	3x7	21	2.0	3,630
*A	3x7	21	13.0	22,220
*B	3x7	21	20.0	36,300
C	10x10	100	4.0	34,600
*C	10x10	100	9.0	77,800
D	12x12	144	4.0	49,700
*D	12x12	144	9.0	112,000

Infiltration (Btu/hr) = 1.08 (cfm/sq-ft)(sq-ft of door)(temp. diff.)

Door Nomenclature

A. Ordinary wooden door

B. All glass door

C. Garage and shipping room door 10 ft. x 10 ft.

D. Garage and shipping room door 12 ft. x 12 ft.

* Denotes average usage for that door.

Lack of an asterisk denotes little or no usage.

Table 15 Window Construction Schedule

Schedule Letter	Dimensions (feet)	Area (sq-ft)	Crack Footage	Infiltration (cfm/ft)	Infiltration with 80 F temp. diff. (Btu/hr)
J	1x3	3	9	.65	505
K	3x3	9	8	1.47	1,015
L	4x4	16	11	1.47	1,395
M	3x6	18	21	.65	1,180
N	4x8	32	28	.65	1,572
*O	6x6	36	24	.183	380
*P	6x8	48	28	.183	443

Infiltration (Btu/hr) = 1.08(cfm/ft crack)(crack footage)(temp. diff.)

Window Nomenclature

J. Double Hung Wood Sash Window (unlocked) Average fit, 1x3 ft.

K. Projected 3x3 ft., opening 1x3 ft.

L. Projected 4x4 ft., opening $1\frac{1}{2}$x4 ft.

M. Double Hung Wood Sash Window (unlocked) Average fit, 3x6 ft.

N. Double Hung Wood Sash Window (unlocked) Average fit, 4x8 ft.

*O. Glass Panels Wood Frame 6x6 ft.

*P. Glass Panels Wood Frame 6x8 ft.

* These windows are permanent glass panels and infiltration is limited to cracks between the frame and the masonry building. The coefficient selected is the average between calked and non-calked frames.

Table 16 Wall Construction Schedule

Schedule Designator	Wall Construction	U(Btu/hr sq-ft F)
W1	4 in. common brick and 8 in. concrete block cinder aggregate with no interior finish.	0.29
W2	Same as W1 but with metal lath and $\frac{3}{4}$ in. plaster on furring interior finish.	0.21
W3	8 in. poured concrete 80 lb/cu-ft, no interior finish.	0.25
W4	Same as W3 but with 5/8 in. plaster interior finish.	0.23
W5	8 in. hollow concrete block, cinder aggregate with no interior finish.	0.32
W6	3/8 in. corrugated transite with $\frac{1}{2}$ in. insulation board.	0.34
W7	24 gauge corrugated iron with $1\frac{1}{2}$ in. insulation board.	0.18
Glass	Vertical glass sheets	
	Single sheet	1.13
	Two sheets with 4 in. space	0.53
Hangar Doors	16 leave Hangar Door containing 60% glass and 40% sheet metal backed by $\frac{1}{2}$ in. of insulation	0.82

$$\frac{6(1.13) + 4(.35)}{10} = \frac{6.78 + 1.40}{10} = .818$$

Table 17 Roof Construction Schedule

Schedule Designator	Roof Construction	U(Btu/hr sq-ft F)
R1	4 in. concrete, built up roofing, 2 in. insulation with no interior finish.	0.15
R2	4 in. concrete, built up roofing, 2 in. insulation, $\frac{3}{4}$ in. sand aggregate plaster on suspended metal lath interior finish.	0.08
R3	4 in. concrete, built up roofing, 2 in. insulation with suspended acoustic tile ceiling.	0.07
R4	Hangar roof, built up roofing with 2 in. insulation.	0.11
R5	Warehouse roof, built up roofing with $1\frac{3}{4}$ in. insulation.	0.13
R6	24 gauge corrugated iron with $1\frac{1}{2}$ in. insulation.	0.18

Table 18 Floor Construction Schedule

Schedule Designator	Floor Construction	U(Btu/hr sq-ft F)
F1	4 in. concrete with no ceiling underneath and with or without asphalt tile above a crawl space.	0.64
F2	6 in. concrete with no ceiling underneath and with or without asphalt tile above a crawl space.	0.57
F3	6 in. concrete with asphalt tile on 5/8 in. plywood on 2x2 in. sleepers above crawl space.	0.29
F4	Concrete slab placed on grade with 2 in. perimeter insulation.	-
F5	Hangar Deck slab of thickness based on wheel loading placed on grade with 2 in. perimeter insulation.	-

IV. Design Heat Transmission and Infiltration Losses for Individual Buildings.

A. Building number 1

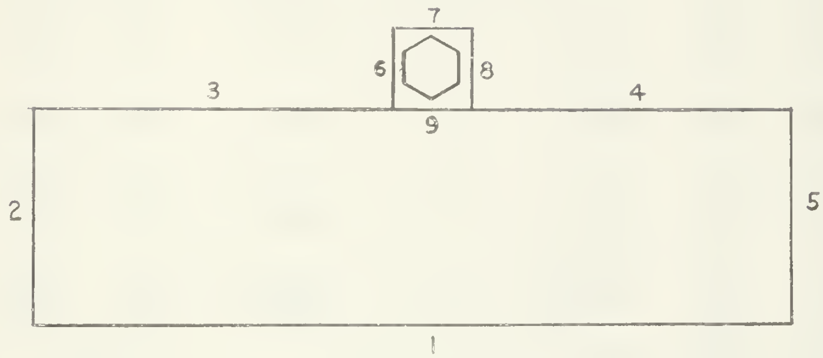

Figure IX

Operations Building and Control Tower

Operations Building

Exposure	Construction	Windows	Doors
1	W1	50 K	4 *A
2	W1	6 K	2 A
3	W1	12 K, 9 *O	2 *A
4	W1	16 K	2 *A
5	W1	6 K	2 A
floor	F2	-	-
roof	R3	-	-

Control Tower

Exposure	Construction	Windows	Doors
6	W1	3 K	-
7	W1	6 K	1 A
8	W1	3 K	-
9	W1	-	-
floor	F2	-	-
roof	R3	-	-
observation glass	double, tinted glass, 1100 sq-ft, U=.53 Btu/hr sq-ft F		

Heating Loss - Operations Building

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
1	200	20	4,000	450	3,550	.29	80	82,300
* 1G					450	1.13	80	40,700
2	60	20	1,200	54	1,146	.29	80	26,550
2G					54	1.13	80	4,880
3	90	20	1,800	432	1,368	.29	80	31,700
3G					432	1.13	80	39,000
4	90	20	1,800	144	1,656	.29	80	38,400
4G					144	1.13	80	13,000
5	60	20	1,200	54	1,146	.29	80	26,550
5G					54	1.13	80	4,880
roof	200	60	12,000		12,000	.07	80	67,250
floor	200	60	12,000		12,000	.57	18	123,100
								498,310

Heating Loss - Control Tower

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
6	20	50	1,000	27	973	.29	80	22,550
6G					27	1.13	80	2,440
7	20	50	1,000	54	946	.29	80	21,950
7G					54	1.13	80	4,880
8	20	50	1,000	27	973	.29	80	22,550
8G					27	1.13	80	2,440
9	20	30	600		600	.29	80	13,900
roof	20	20	400		400	.07	80	2,240
floor	20	20	400		400	.57	18	4,100
tower glass	6	60	360	360	360	.53	80	16,280
								112,330

* The G indicates glass only for that exposure. This notation will be repeated for each building exposure with glass.

[illegible]

Infiltration Heating Loss - Operations Building

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
56 K		1,015	56,800
	4 *A	22,220	88,880
	2 A	3,630	7,260
			152,940

Exposures 6 and 9

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
3 K		1,015	3,045
	1 A	3,630	3,630
			6,675

B. Building number 2

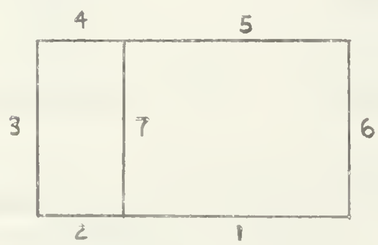

Figure X

Fire and Crash Trucks Building

Exposure	Construction	Windows	Doors
1	W3	-	2 D, 1*D
2	W3	3 K	1*A
3	W3	4 K	1 A
4	W3	3 K	1 A
5	W3	8 K	-
6	W3	-	-
7	W5	-	-
roof	R1	-	-
floor	F4	-	-

Heating Loss - Fire and Crash Trucks Building

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
1	50	14	700	250	450	.25	74	8,320
1G					250	1.13	74	20,900
2	20	10	200	27	173	.25	80	3,460
2G					27	1.13	80	2,440
3	36	10	360	36	324	.25	80	6,480
3G					36	1.13	80	3,250
4	20	10	200	27	173	.25	80	3,460
4G					27	1.13	80	2,440
5	50	14	700	72	628	.25	74	11,620
5G					72	1.13	74	6,020
6	36	14	504		504	.25	74	9,320
7	36	4	144		144	.32	74	3,410
roof	50	36	1,800		1,800	.15	74	20,000
roof	20	36	720		720	.15	80	8,640
floor	70	36	perimeter = 212,		212(40) =			8,480
								117,840

Infiltration Heating Loss - Fire and Crash Trucks Building

Exposures 1, 2 and 6

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
3 K		1,015	3,045
	1 *A	22,220	22,220
	2 D, 1 *D	**	89,500
			114,765

Q(Btu/hr) = (Volume)(density air)(specific heat of air)(temp. diff.)(air changes/hr)

Q = (25,200 cu-ft)(.080 lb mass/cu-ft)(.240 Btu/lb mass F)(74 F)(2.5/hr)

Q = 89,500 Btu/hr

** The unit infiltration loss for the D type doors is not applicable to this building because all three of the doors are on one exposure. The infiltration has been calculated based on two changes of air per hour to compensate for door opening and closing and one-half change of air per hour due to infiltration.

C. Building number 3

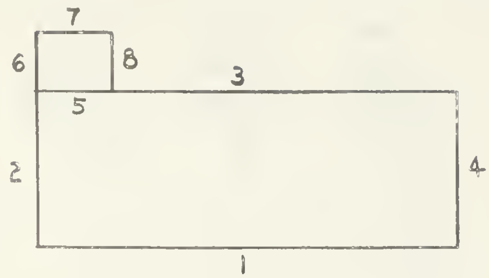

Figure XI

Parachute Building and Drying Tower

Parachute Building

Exposure	Construction	Windows	Doors
1	W3	10 K	1 A, 1 *A
2	W3	6 K	-
3	W3	8 K	1 A
4	W3	6 K	-
roof	R1	-	-
floor	F2	-	-

Drying Tower

Exposure	Construction	Windows	Doors
5	W3	-	-
6	W3	-	-
7	W3	-	-
8	W3	-	-
roof	R1	-	-
floor	F4	-	-

Heating Loss - Parachute Building

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
1	100	12	1,200	90	1,110	.25	80	22,200
1G					90	1.13	80	8,110
2	60	12	720	54	666	.25	80	13,320
2G					54	1.13	80	4,870
3	84	12	1,008	72	936	.25	80	18,720
3G					72	1.13	80	6,480
4	60	12	720	54	666	.25	80	13,320
4G					54	1.13	80	4,870
roof	100	60	6,000		6,000	.15	80	72,000
floor	100	60	6,000		6,000	.57	18	61,520
								225,420

Heating Loss - Drying Tower

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
5	16	24	384		384	.25	80	7,680
6	16	36	576		576	.25	80	11,520
7	16	36	576		576	.25	80	11,520
8	16	36	576		576	.25	80	11,520
roof	16	16	256		256	.15	80	3,070
floor	16	16	perimeter = 64, 64(40) =					2,560
								47,870

Infiltration Heating Loss - Parachute Building

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
16 K		1,015	16,250
	1 A	3,630	3,630
	1 *A	22,220	22,220
			42,100

D. Building number 4

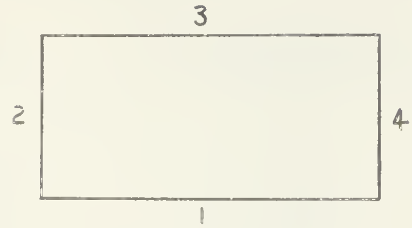

Figure XII

Training Building

Exposure	Construction	Windows	Doors
1	W3	38 L	1 A, 1 *A
2	W3	20 L	2 A
3	W3	40 L, 4 J	-
4	W3	20 L	2 A
roof	R3	-	-
floor	F2	-	-

Heating Loss - Training Buildings

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
1	120	20	2,400	608	1,792	.25	80	35,840
1G					608	1.13	80	55,000
2	75	20	1,500	320	1,180	.25	80	23,600
2G					320	1.13	80	28,900
3	120	20	2,400	640	1,760	.25	80	35,200
3G					640	1.13	80	57,800
4	75	20	1,500	320	1,180	.25	80	23,600
4G					320	1.13	80	28,900
roof	120	75	9,000		9,000	.07	80	50,400
floor	120	75	9,000		9,000	.57	18	92,300
								431,540

Infiltration Heating Loss - Training Building

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
58 L		1,395	80,800
	1 A	3,630	3,630
	1 *A	22,220	22,220
			106,650

E. Building number 5

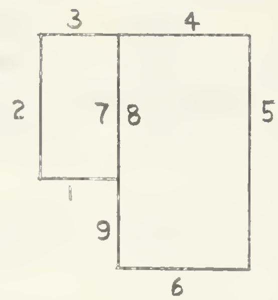

Figure XIII

Maintenance Hangar and Maintenance Shops

Maintenance Shops

Exposure	Construction	Windows	Doors
1	W3	26 K	1 A, 1 *A
2	W3	50 K	1 *A
3	W3	26 K	1 A, 1 C
8	W5	-	4 A, 1 C
roof	R1	-	-
floor	F4	-	-

Maintenance Hangar

Exposure	Construction	Windows	Doors
4	W7	-	2 A
5	W7	-	2 A
6	W7	-	Hangar Door
7	W7	-	-
9	W7	-	1 *A
roof	R4	-	-
floor	F5	-	-

Calculations for Hangar and Arc

Radius of Roof Arc = 259 ft

Angle of Sector = 45.5 Deg = .794 Rad = A.S.

Area of Arc Face = $\frac{1}{2}$(R)(R)(A.S. - Sin A.S.)

= $\frac{1}{2}$(259)(259)(.794 - .713)

= 2,710 sq-ft

Length of Roof Arc = R(A.S.) = (259)(.794)

= 206 ft

Heating Loss - Maintenance Shops

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
1	100	20	2,000	234	1,766	.25	74	32,620
1G					234	1.13	74	20,300
2	200	20	4,000	540	3,460	.25	74	64,000
2G					540	1.13	74	45,100
3	100	20	2,000	234	1,766	.25	74	32,620
3G					234	1.13	74	20,300
8	200	20	4,000		4,000	.32	5	6,400
roof	100	200	20,000		20,000	.75	74	222,200
floor	100	200	perimeter = 600,		600(40)=			24,000
								467,540

Heating Loss - Maintenance Hangar

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
4	200	40+Arc	10,710		10,710	.18	69	133,100
5	300	40	12,000		12,000	.18	69	149,100
6	Roof Arc		2,710		2,710	.18	69	33,600
6D	Hangar Door		8,000		8,000	.82	69	452,500
7	200	20	4,000		4,000	.18	69	49,700
8	200	20	4,000		4,000	.32	-5	-6,400
9	100	40	4,000		4,000	.18	69	49,700
roof	206	300	61,800		61,800	.11	69	468,000
floor	200	300	perimeter = 1,000,		1,000(40) =			40,000
								1,369,300

Infiltration Heating Loss - Maintenance Shops

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
76 K		1,015(74/80)	71,500
	1 A	3,630(74/80)	3,360
	2 *A	22,220(74/80)	41,100
			115,960

Infiltration Heating Loss - Maintenance Hangar

The presence of the one large 16 leave hangar door makes it impractical to calculate infiltration by the crack method. It is assumed that the infiltration will equal 1 air change per hour.

Q(Btu/hr) = (Volume)(Density air)(specific heat of air)(temp. diff.)(air changes/hr)

Q = (3,213,000 cu-ft)(.080 lb mass/cu-ft)(.240 Btu/lb mass F)(69 F)(1 air change/hr)

Q = 4,260,000 Btu/hr

F. Building number 6

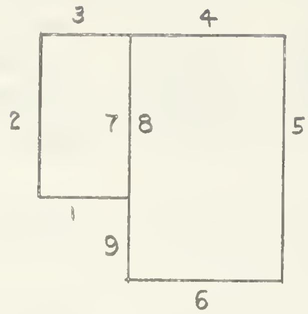

Figure XIV

Operational Hangar and Offices

Offices

Exposure	Construction	Windows	Doors
1	W4	16 K	1 A, 1 *A
2	W4	36 K	1 *A
3	W4	16 K	1 A, 1 *A
8	W5	-	2 A
roof	R2	-	-
floor	F4	-	-

Operational Hangar

Exposure	Construction	Windows	Doors
4	W7	-	2 A
5	W7	-	2 A
6	W7	-	Hangar Door
7	W7	-	-
9	W7	-	1 *A
roof	R4	-	-
floor	F5	-	-

Heating Loss - Offices

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
1	100	10	1,000	144	856	.23	80	15,770
1G					144	1.13	80	13,020
2	200	10	2,000	324	1,676	.23	80	30,850
2G					324	1.13	80	29,300
3	100	10	1,000	144	856	.23	80	15,770
3G					144	1.13	80	13,020
8	200	10	2,000		2,000	.32	11	7,040
roof	200	100	20,000		20,000	.08	80	128,000
floor	200	100	perimeter = 600,		600(40) =			24,000
								276,770

Heating Loss - Operational Hangar

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load Btu/hr
4	200 x 40+Arc		10,710		10,710	.18	69	133,100
5	300	40	12,000		12,000	.18	69	149,100
6	Roof Arc		2,710		2,710	.18	69	33,600
6D	Hangar Door		88,000		88,000	.82	69	452,500
7	200	30	6,000		6,000	.18	69	74,500
8	200	10	2,000		2,000	.32	-11	-7,000
9	100	40	4,000		4,000	.18	69	49,700
roof	206	300	61,800		61,800	.11	69	468,000
floor	200	300	perimeter = 1,000,		1,000(40) =			40,000
								1,393,500

Infiltration Heating Loss - Offices

Windows	Doors		Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
52 K			1,015	52,750
	1	A	3,630	3,630
	2	*A	22,220	44,440
				100,820

Infiltration Heating Loss - Operation Hangar

Calculations are identical to those made for the Maintenance Hangar.

$$Q = 4,260,000 \text{ Btu/hr}$$

G. Building number 7

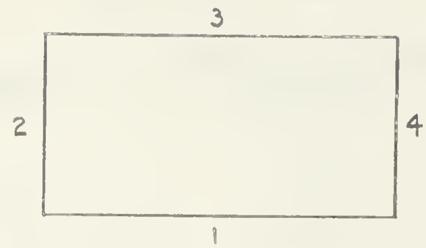

Figure XV

Aviation Supply Warehouse

Exposure	Construction	Windows	Doors
1	W5	6 L	2 C, 1*C, 1 D
2	W5	-	1 A
3	W5	6 L	2 C, 1*C, 1 D
4	W5	-	1 A
roof	R5	-	-
floor	F4	-	-

Heating Loss - Aviation Supply Warehouse

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	210	20	4,200	96	4,104	.32	69	90,500
1G					96	1.13	69	7,500
2	180	20	3,600		3,600	.32	69	79,500
3	210	20	4,200	96	4,104	.32	69	90,500
3G					96	1.13	69	7,500
4	180	20	3,600		3,600	.32	69	79,500
roof	185	210	38,850		38,850	.13	69	348,000
floor	180	210	perimeter = 780,		780(40) =			31,200
								734,200

Infiltration Heating Loss - Aviation Supply Warehouse

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
6 L		1,395	8,280
	1 A	3,630	3,630
	2 C	34,600	69,200
	1*C	77,800	77,800
	1 D	49,700	49,700
			208,610 (69/80)
			=180,000

H. Building number 8

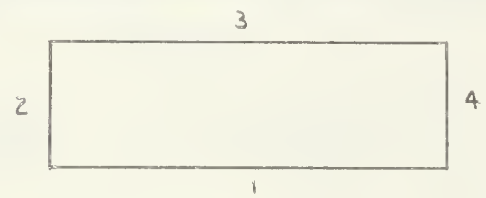

Figure XVI

General Supply Warehouse

Exposure	Construction	Windows	Doors
1	W5	6 L	1 C, 1*C, 1 D
2	W5	-	1 A
3	W5	6 L	1 C, 1*C, 1 D
4	W5	-	1 A
roof	R5	-	-
floor	F4	-	-

Heating Loss - General Supply Warehouse

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	210	20	4,200	96	4,104	.32	69	90,500
1G					96	1.13	69	7,500
2	90	20	1,800		1,800	.32	69	39,750
3	210	20	4,200	96	4,104	.32	69	90,500
3G					96	1.13	69	7,500
4	90	20	1,800		1,800	.32	69	39,750
roof	93	210	19,530		19,530	.13	69	175,000
floor	90	210	perimeter = 600,		600(40) =			24,000
								474,500

Infiltration Heating Loss - General Supply Warehouse

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
6 L		1,395	8,280
	1 A	3,630	3,630
	1 C	34,600	34,600
	1*C	77,800	77,800
	1 D	49,700	49,700
			174,010 (69/80)
			= 150,100

I. Building number 9

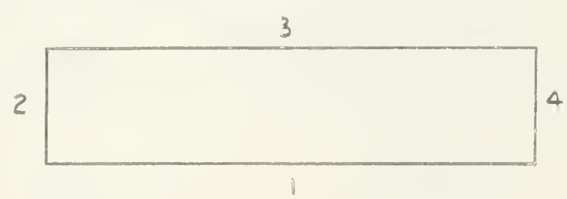

Figure XVII

Flammable Supply Warehouse

Flammable Supply Warehouse

Exposure	Construction	Windows	Doors
1	W5	2 L	1 C, 1*C
2	W5	-	-
3	W5	2 L	1 C, 1 D
4	W5	-	-
roof	R1	-	-
floor	F4	-	-

Heating Loss - Flammable Supply Warehouse

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	180	20	3,600	32	3,568	.32	69	78,750
1G					32	1.13	69	2,490
2	45	20	900		900	.32	69	19,870
3	180	20	3,600	32	3,568	.32	69	78,750
3G					32	1.13	69	2,490
4	45	20	900		900	.32	69	19,870
roof	180	45	8,100		8,100	.15	69	84,000
floor	180	45	perimeter = 450,		450(40) =			18,000
								304,220

Infiltration Heating Loss - Flammable Supply Warehouse

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
2 L		1,395	2,790
	1 C	34,600	34,600
	1*C	77,800	77,800
			115,190 (69/80)
			= 99,200

J. Building number 10

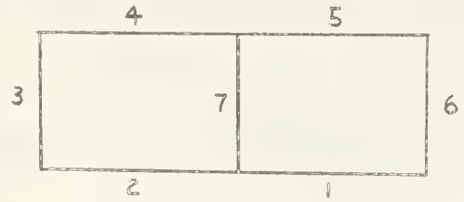

Figure XVIII

Fire Station

Exposure	Construction	Windows	Doors
1	W3	-	2 D, 1*D
2	W3	6 K	1*A
3	W3	4 K	1 A
4	W3	6 K	1 A
5	W3	8 K	-
6	W3	-	-
7	W5	-	-
roof	R1	-	-
floor	F4	-	-

Heating Loss - Fire Station

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	45	14	630	250	380	.25	74	7,000
1G					250	1.13	74	20,900
2	45	10	450	54	396	.25	80	7,920
2G					54	1.13	80	4,880
3	62	10	620	36	584	.25	80	11,680
3G					36	1.13	80	3,250
4	45	10	450	54	396	.25	80	7,920
4G					54	1.13	80	4,880
5	45	14	630	72	558	.25	74	10,320
5G					72	1.13	74	6,020
6	62	14	868		868	.25	74	10,280
7	62	4	248		248	.32	74	5,870
roof	62	45	2,790		2,790	.15	74	30,950
roof	62	45	2,790		2,790	.15	80	33,500
floor	90	62	perimeter = 304,		304(40) =			12,160
								166,820

Infiltration Heating Loss - Fire Station

Exposures 1, 2 and 6

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
6 K		1,015	6,090
	1*A	22,220	22,220
	2 D, 1*D	**	143,100
			171,410

Q(Btu/hr) = (Volume)(density air)(specific heat of air)(temp. diff.)(air changes/hr)

Q = (67,000 cu-ft)(.080 lb mass/cu-ft)(.240 Btu/lb mass F)(74 F)(1.5/hr)

Q = 143,100 Btu/hr

K. Building number 11

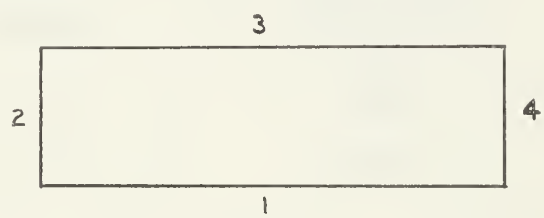

Figure XIX

Ordnance Shop

Exposure	Construction	Windows	Doors
1	W3	-	1 C, 1 A
2	W3	-	1 A
3	W3	14 K	1*A
4	W3	8 K	-
roof	R1	-	-
floor	F4	-	-

** The unit infiltration loss for the D type doors is not applicable to this building because all three of the doors are on one exposure. The infiltration has been calculated based on one change of air per hour to compensate for door opening and closing and one-half change of air per hour due to infiltration.

Heating Loss - Ordnance Shop

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	140	12	1,680		1,680	.25	74	31,400
2	75	12	900		900	.25	74	16,670
3	140	12	1,680	126	1,554	.25	74	28,780
3G					126	1.13	74	10,540
4	75	12	900	72	828	.25	74	15,320
4G					72	1.13	74	6,020
roof	140	75	10,500		10,500	.15	74	116,600
floor	140	75	perimeter = 330,		330(40) =			13,200
								238,530

Infiltration Heating Loss - Ordnance Shop

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
8 K		1,015	8,120
	1 A	3,630	3,630
	1 C	34,600	34,600
			46,350 (74/80)
			= 42,400

L. Building number 12

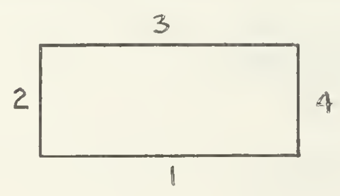

Figure XX

Paint and Dope Shop

Paint and Dope Shop

Exposure	Construction	Windows	Doors
1	W7	10 K	1 A
2	W7	-	1 C
3	W7	10 K	1 A
4	W7	-	1 C
roof	R6	-	-
floor	F4	-	-

Heating Loss - Paint and Dope Shop

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	100	10	1,000	90	910	.18	89	14,600
1G					90	1.13	89	9,050
2	60	10	600		600	.18	89	9,620
3	100	10	1,000	90	910	.18	89	14,600
3G					90	1.13	89	9,050
4	60	10	600		600	.18	89	9,620
roof	100	60	6,000		6,000	.18	89	96,200
floor	100	60	perimeter = 320,		320(40) =			12,800
								165,540

Infiltration Heating Loss - Paint and Dope Shop

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
10 K		1,015	10,150
	1 A	3,630	3,630
	1 C	34,600	34,600
			48,380 (89/80)
			= 53,800

M. Building number 20

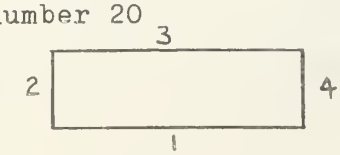

Figure XXI

Dispensary

Dispensary

Exposure	Construction	Windows	Doors
1	W2	12 M	1 A, 1*A
2	W2	6 M, 2 J	1 A
3	W2	14 M	2 A
4	W2	6 M, 2 J	1 A
roof	R3	-	-
floor	F3	-	-

Heating Loss - Dispensary

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	85	10	850	216	634	.21	84	11,200
1G					216	1.13	84	20,500
2	60	10	600	114	486	.21	84	8,560
2G					114	1.13	84	10,800
3	85	10	850	252	634	.21	84	11,200
3G					252	1.13	84	20,500
4	60	10	600	114	486	.21	84	8,560
4G					114	1.13	84	10,800
roof	85	60	5,100		5,100	.07	84	[illegible]
floor	85	60	5,100		5,100	.29	34	50,200
								182,320

Infiltration Heating Loss - Dispensary

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
2 J		505	1,010
18 M		1,180	21,220
	2 A	3,630	7,260
	1*A	22,220	22,220
			51,710 (84/80)
			= 54,300

N. Building number 21

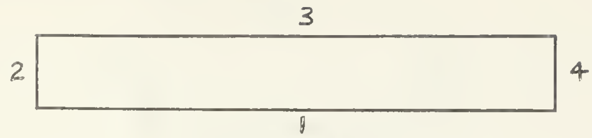

Figure XXII

Administration Building

Exposure	Construction	Windows	Doors
1	W2	48 M, 2*P	2*A
2	W2	8 M	2 A
3	W2	48 M	2*A
4	W2	8 M	2 A
roof	R3	-	-
floor	F3	-	-

Heating Loss - Administration Building

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	360	20	7,200	960	6,240	.21	80	105,000
1G					960	1.13	80	86,800
2	60	20	1,200	144	1,056	.21	80	17,720
2G					144	1.13	80	13,020
3	360	20	7,200	864	6,336	.21	80	106,500
3G					864	1.13	80	78,000
4	60	20	1,200	144	1,056	.21	80	17,720
4G					144	1.13	80	13,020
roof	360	60	21,600		21,600	.07	80	122,000
floor	360	60	21,600		21,600	.29	30	188,000
								747,780

Infiltration Heating Loss - Administration Building

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
56 M		1,180	66,000
2*P		443	890
	2*A	22,220	44,440
	2 A	3,630	7,260
			118,590

O. Building number 22

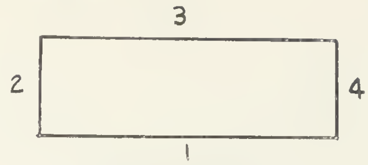

Figure XXIII

All Faith Chapel

Exposure	Construction	Windows	Doors
1	W2	6 N, 2 M	1 A
2	W2	2 M	1 A, 1*A
3	W2	6 N, 2 M	1 A
4	W2	2 M	-
roof	R3	-	-
floor	F3	-	-

Heating Loss - All Faith Chapel

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	120	16	1,920	228	1,692	.21	80	28,400
1G					228	1.13	80	20,800
2	70	16	1,120	36	1,084	.21	80	18,200
2G					36	1.13	80	3,250
3	120	16	1,920	228	1,692	.21	80	28,400
3G					228	1.13	80	20,600
4	70	16	1,120	36	1,084	.21	80	18,200
4G					36	1.13	80	3,250
roof	120	70	8,400		8,400	.07	80	47,100
floor	120	70	perimeter = 380,		380(40) =			15,200
								203,400

Infiltration Heating Loss - All Faith Chapel

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
6 N		1,572	9,430
4 M		1,180	4,720
	2 A	3,630	7,260
	1*A	22,220	22,220
			43,630

P. Building number 23

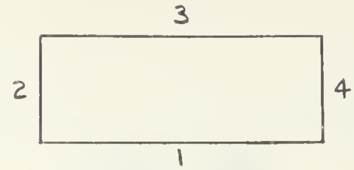

Figure XXIV

Auditorium

Exposure	Construction	Windows	Doors
1	W4	40 K	2 A, 1*A
2	W4	2 L	1 A, 1 C
3	W4	40 L	2 A
4	W4	2 L	2 A
roof	R6	-	-
floor	F4	-	-

Heating Loss - Auditorium

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	160	20	3,200	360	2,840	.23	74	48,400
1G					360	1.13	74	30,050
2	100	20	2,000	32	1,968	.23	74	33,500
2G					32	1.13	74	2,670
3	160	20	3,200	360	2,840	.23	74	48,400
3G					360	1.13	74	30,050
4	100	20	2,000	32	1,968	.23	74	33,500
4G					32	1.13	74	2,670
roof	160	100	16,000		16,000	.18	74	213,000
floor	160	100	perimeter = 520,		520(40) =			20,800
								463,040

Infiltration Heating Loss - Auditorium

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
40 L		1,015	40,600
2 L		1,395	2,790
	3 A	3,630	10,890
	1*A	22,220	22,220
	1 C	34,600	34,600
			111,100 (74/80)
			= 102,800

Q. Building number 24

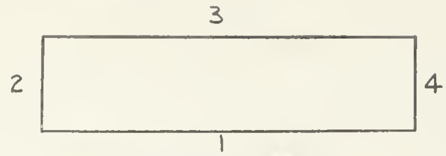

Figure XXV

Navy Exchange

Exposure	Construction	Windows	Doors
1	W4	16 J	1*B
2	W4	-	-
3	W4	16 J	1 A, 1 C
4	W4	-	-
roof	R3	-	-
floor	F4	-	-

Heating Loss - Navy Exchange

Exposure	Dimensions (ft)	(ft)	(sq-ft)	(sq-ft)	(sq-ft)	U	Temp. Diff. (F)	(Btu/hr)
1	180	10	1,800	48	1,752	.23	80	32,250
1G					48	1.13	80	4,340
2	60	10	600		600	.23	80	11,050
3	180	10	1,800	48	1,752	.23	80	32,250
3G					48	1.13	80	4,340
4	60	10	600		600	.23	80	11,050
roof	180	60	10,800		10,800	.07	80	60,500
floor	180	60	perimeter = 480,		480(40) =			19,200
								174,980

Infiltration Heating Loss - Navy Exchange

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
16 J		505	8,080
	1*B	36,300	36,300
			44,380

R. Building numbers 25, 26, 27, 28, 29, 30, 31, and 32

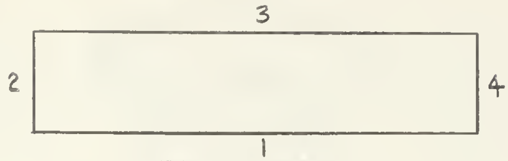

Figure XXVI

E. M. Barracks

Exposure	Construction	Windows	Doors
1	W4	88 K	1 A, 1*A
2	W4	3 J	3 A
3	W4	88 K	1 A, 1*A
4	W4	3 J	3 A
roof	R2	-	-
floor	F3	-	-

Heating Loss - E. M. Barracks

Exposure	Dimensions (ft)	(ft)	(sq-ft)	(sq-ft)	(sq-ft)	U	Temp. Diff. (F)	(Btu/hr)
1	221	30	6,630	792	5,838	.23	80	107,400
1G					792	1.13	80	71,600
2	32	30	960	9	959	.23	80	17,680
2G					9	1.13	80	810
3	221	30	6,630	792	5,838	.23	80	107,400
3G					792	1.13	80	71,600
4	32	30	960	9	950	.23	80	17,680
4G					9	1.13	80	810
roof	221	32	7,072		7,072	.08	80	45,200
floor	221	32	7,072		7,072	.29	30	61,500
								501,680

Infiltration Heating Loss - E. M. Barracks

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
88 K		1,015	89,300
3 J		505	2,020
	4 A	3,630	14,520
	1*A	22,220	22,220
			128,060

S. Building number 33

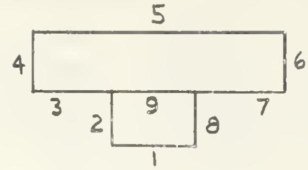

Figure XXVII

E. M. Mess and Galley

E. M. Mess

Exposure	Construction	Windows	Doors
3	W4	-	2 A
4	W4	2*P	-
5	W4	10*0	3 A, 3*A
6	W4	2*P	-
7	W4	-	2 A
9	W4	-	-
roof	R3	-	-
floor	F4	-	-

E. M. Galley

Exposure	Construction	Windows	Doors
1	W4	3 K	1 A, 1*A
2	W4	4 K	-
8	W4	8 K	-
roof	R2	-	-
floor	F2	-	-

Heating Loss - E. M. Mess

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
3	50	14	700		700	.23	80	12,890
4	80	14	1,120	96	1,024	.23	80	18,820
4G					96	1.13	80	8,660
5	180	14	2,520	360	2,160	.23	80	39,720
5G					360	1.13	80	32,500
6	80	14	1,120	96	1,024	.23	80	18,820
6G					96	1.13	80	8,660
7	50	14	700		700	.23	80	12,890
9	80	2	90		90	.23	80	1,660
roof	180	80	14,400		14,400	.07	80	80,700
floor	180	80	perimeter = 520,		520(40) =			20,800

Heating Loss - E. M. Galley

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	80	12	960	27	933	.23	80	17,200
1G					27	1.13	80	2,440
2	100	12	1,200	36	1,164	.23	80	21,420
2G					36	1.13	80	3,250
8	100	12	1,200	72	1,128	.23	80	20,750
8G					72	1.13	80	6,500
roof	100	80	8,000		8,000	.08	80	51,200
floor	100	80	8,000		8,000	.57	18	82,200
								204,960

Infiltration Heating Loss - E. M. Mess and Galley

Exposures 5, 6, 7 and 8

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
10 *O		380	3,800
2 *P		433	870
8 K		1,015	8,130
	5 A	3,630	18,150
	3*A	22,220	66,660
			97,610

T. Building number 34

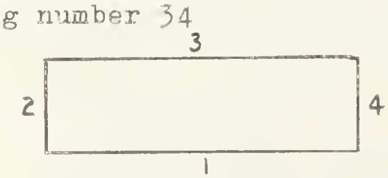

Figure XXVIII

E. M. Club

Exposure	Construction	Windows	Doors
1	W4	2*O, 8 K	1*A, 1 A
2	W4	-	1 A
3	W4	2*O, 18 K	1 A
4	W4	-	2 A
roof	R3	-	-
floor	F4	-	-

Heating Loss - E. M. Club

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	160	12	1,920	144	1,776	.23	80	32,650
1G					144	1.13	80	13,010
2	96	12	1,152		1,152	.23	80	21,200
3	160	12	1,920	234	1,686	.23	80	31,000
3G					234	1.13	80	21,180
4	96	12	1,152		1,152	.23	80	21,200
roof	160	96	15,380		15,380	.07	80	86,000
floor	160	96	perimeter = 512,		512(40) =			20,480
								246,720

Infiltration Heating Loss - E. M. Club

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
2*O		380	960
8 K		1,015	8,130
	2 A	3,630	7,260
	1*A	22,220	22,220
			38,570

U. Building number 35

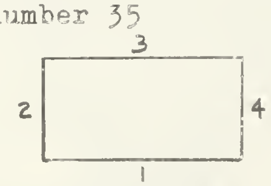

Figure XXIX

C. P. O. Club

Exposure	Construction	Windows	Doors
1	W4	8 K	1*A, 1 A
2	W4	-	1 A
3	W4	2*O, 12 K	1 A
4	W4	-	1 A
roof	R3	-	-
floor	F4	-	-

Heating Loss - C. P. O. Club

Exposure	Dimensions (ft)	(ft)	(sq-ft)	(sq-ft)	(sq-ft)	U	Temp. Diff. (F)	(Btu/hr)
1	96	12	1,152	72	1,080	.23	80	19,890
1G					72	1.13	80	6,500
2	96	12	1,152		1,152	.23	80	21,220
3	96	12	1,152	180	972	.23	80	17,900
3G					180	1.13	80	16,250
4	96	12	1,152		1,152	.23	80	21,220
roof	96	96	9,120		9,120	.07	80	51,000
floor	96	96	perimeter = 384,		384(40) =			15,360
								169,340

Infiltration Heating Loss - C. P. O. Club

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
8 K		1,015	8,130
	2 A	3,630	7,260
	1*A	22,220	22,220
			37,610

V. Building number 36

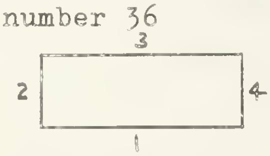

Figure XXX

Laundry

Exposure	Construction	Windows	Doors
1	W3	12 L, 1 J	-
2	W3	4 L	1 A, 1*A
3	W3	12 L, 1 J	-
4	W3	4 L	1 C, 1 A
roof	R1	-	-
floor	F4	-	-

Heating Loss - Laundry

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	100	14	1,400	195	1,205	.25	80	24,100
1G					195	1.13	80	17,600
2	60	14	840	64	776	.25	80	15,520
2G					64	1.13	80	5,780
3	100	14	1,400	195	1,205	.25	80	24,100
3G					195	1.13	80	17,600
4	60	14	840	64	776	.25	80	15,520
4G					64	1.13	80	5,780
roof	100	60	6,000		6,000	.15	80	72,000
floor	100	60	perimeter = 320,		320(40) =			12,800
								210,800

Infiltration Heating Loss - Laundry

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
16 L		1,395	22,300
1 J		505	500
	1 A	3,630	3,630
	1*A	22,220	22,220
			48,650

W. Building number 37

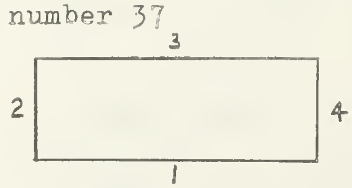

Figure XXXI

Brig

Exposure	Construction	Windows	Doors
1	W3	8 K	1 A
2	W3	4 K	1 A
3	W3	8 K	-
4	W3	4 K	1 A
roof	R1	-	-
floor	F4	-	-

Heating Loss - Brig

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	96	10	960	72	888	.25	80	17,760
1G					72	1.13	80	6,510
2	32	10	320	32	888	.25	80	5,760
2G					32	1.13	80	2,890
3	96	10	960	72	888	.25	80	17,760
3G					72	1.13	80	6,510
4	32	10	320	32	288	.25	80	5,760
4G					32	1.13	80	2,890
roof	96	32	3,072		3,072	.15	80	36,800
floor	96	32	perimeter = 256,		256(40) =			10,240
								112,880

Infiltration Heating Loss - Brig

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
12 K		1,015	12,180
	1 A	3,630	3,630
			15,810

X. Building number 38

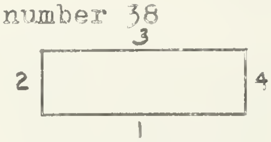

Figure XXXII

Hobby Shop

Exposure	Construction	Windows	Doors
1	W5	8 K, 2 J	1*A
2	W5	2 K	1 A
3	W5	6 K	2 A
4	W5	2 K	1 A
roof	R1	-	-
floor	F4	-	-

Heating Loss - Hobby Shop

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	96	10	960	78	882	.32	80	22,600
1G					78	1.13	80	7,050
2	48	10	480	18	462	.32	80	11,820
2G					18	1.13	80	1,630
3	96	10	960	54	906	.32	80	23,200
3G					54	1.13	80	4,880
4	48	10	480	18	462	.32	80	11,820
4G					18	1.13	80	1,630
roof	96	48	4,610		4,610	.15	80	55,250
floor	96	48	perimeter = 288,		288(40) =			11,520
								151,400

Infiltration Heating Loss - Hobby Shop

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
10 K		1,015	10,150
2 J		505	1,010
	1 A	3,630	3,630
	1*A	22,220	22,220
			37,010

Y. Building numbers 39, 40 and 41

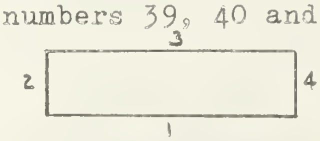

Figure XXXIII

Training Building

Exposure	Construction	Windows	Doors
1	W4	40 K	1 A, 1*A
2	W4	16 K	2 A
3	W4	40 K	1 A, 1*A
4	W4	16 K	2 A
roof	R3	-	-
floor	F3	-	-

Heating Loss - Training Building

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	160	20	3,200	360	2,840	.23	80	52,250
1G					360	1.13	80	32,520
2	60	20	1,200	144	1,056	.23	80	19,400
2G					144	1.13	80	13,030
3	160	20	3,200	360	2,840	.23	80	52,250
3G					360	1.13	80	32,520
4	60	20	1,200	144	1,056	.23	80	19,400
4G					144	1.13	80	13,030
roof	160	60	9,600		9,600	.07	80	53,750
floor	160	60	9,600		9,600	.29	30	83,600
								371,750

Infiltration Heating Loss - Training Building

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
56 K		1,015	56,800
	3 A	3,630	10,890
	1*A	22,220	22,220
			89,910

Z. Building number 42

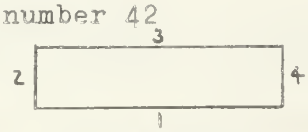

Figure XXXIV

PW Administration

Exposure	Construction	Windows	Doors
1	W4	26 K	1 A, 1*A
2	W4	9 K	1 A
3	W4	26 K	1 A
4	W4	9 K	1 A
roof	R2	-	-
floor	F4	-	-

Heating Loss - PW Administration

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	130	20	2,600	234	2,366	.23	80	43,500
1G					234	1.13	80	21,150
2	48	20	960	81	879	.23	80	16,180
2G					81	1.13	80	7,320
3	130	20	2,600	234	2,366	.23	80	43,500
3G					234	1.13	80	21,150
4	48	20	960	81	879	.23	80	16,180
4G					81	1.13	80	7,320
roof	130	48	6,240		6,240	.08	80	39,900
floor	130	48	perimeter = 356,		356(40) =			14,240
								230,440

Infiltration Heating Loss - PW Administration

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
35 K		1,015	35,520
	2 A	3,630	7,260
	1*A	22,220	22,220
			65,000

AA. Building number 43

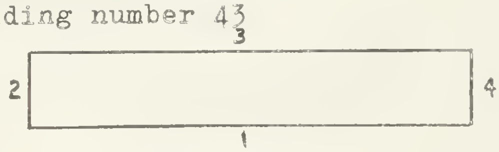

Figure XXXV

PW Transportation

Exposure	Construction	Windows	Doors
1	W5	4 K	1 D, 1 C, 1 A
2	W6	2 K	1 A
3	W5	32 K	2 A
4	W6	2 K	1 A
roof	R6	-	-
floor	F4	-	-

Heating Loss - PW Transportation

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	200	14	2,800	36	2,764	.32	74	65,400
1G					36	1.13	74	3,010
2	40	14	560	18	542	.34	74	13,630
2G					18	1.13	74	1,510
3	200	14	2,800	288	2,764	.32	74	65,400
3G					288	1.13	74	24,100
4	40	14	560	18	542	.34	74	13,630
4G					18	1.13	74	1,510
roof	200	40	8,000		8,000	.18	74	106,600
floor	200	40	perimeter = 480,		480(40) =			19,200
								313,990

Infiltration Heating Loss - PW Transportation

Infiltration is calculated based on two air changes/hour.

Q(Btu/hr) = (Volume)(Density air)(specific heat of air)(temp. diff.)
(air changes/hour)

Q = (112,000 cu-ft)(.080 lb mass/cu-ft)(.240 Btu/lb mass F)
(74 F)(2.0/hr)

Q = 318,000 Btu/hr

BB. Building number 44

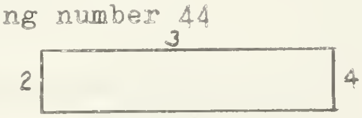

Figure XXXVI

PW Shops

Exposure	Construction	Windows	Doors
1	W5	8 L	1*A, 1 C
2	W5	4 L	1 A
3	W5	8 L	1*A, 1 C
4	W5	4 L	1 A
roof	R1	-	-
floor	F4	-	-

Heating Loss - PW Shops

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	120	14	1,680	128	1,552	.32	74	36,750
1G					128	1.13	74	10,700
2	60	14	840	64	776	.32	74	18,360
2G					64	1.13	74	5,350
3	120	14	1,680	128	1,552	.32	74	36,750
3G					128	1.13	74	10,700
4	60	14	840	64	776	.32	74	18,360
4G					64	1.13	74	5,350
roof	120	60	7,200		7,200	.15	74	79,900
floor	120	60	perimeter = 360,		360(40) =			14,400
								236,620

Infiltration Heating Loss - PW Shops

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
12 L		1,395	16,720
	1 A	3,630	3,630
	1*A	22,220	22,220
	1 C	34,600	34,600
			77,170 (74/80)
			= 71,300

CC. Building number 45

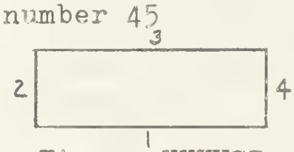

Figure XXXVII

PW Storage

Exposure	Construction	Windows	Doors
1	W5	2 L	1 C, 1 A
2	W5	-	-
3	W5	2 L	1 A
4	W5	-	-
roof	R6	-	-
floor	F4	-	-

Heating Loss - PW Storage

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Loss (Btu/hr)
1	90	14	1,260	32	1,228	.32	74	29,050
1G					32	1.13	74	2,680
2	60	14	840		840	.32	74	19,900
3	90	14	1,260	32	1,228	.32	74	29,050
3G					32	1.13	74	2,680
4	60	14	840		840	.32	74	19,900
roof	90	60	5,400		5,400	.18	74	71,900
floor	90	60	perimeter = 300,		300(40) =			12,000
								187,160

Infiltration Heating Loss - PW Storage

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
2 L		1,395	2,790
	1 C	34,600	34,600
	1 A	3,630	3,630
			41,020 (74/80)
			= 37,900

DD. Building number 46

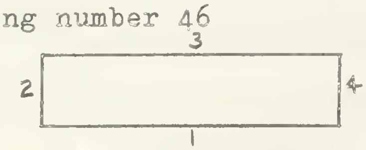

Figure XXXVIII

Heating Plant

Exposure	Construction	Windows	Doors
1	W3	18 K	1*A
2	W3	-	1 A, 1 D
3	W3	18 K	1 A
4	W3	-	1 A
roof	R1	-	-
floor	F4	-	-

Heating Loss - Heating Plant

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	80	20	1,600	162	1,438	.25	80	28,760
1G					162	1.13	80	14,620
2	60	20	1,200		1,200	.25	80	24,000
3	80	20	1,600	162	1,438	.25	80	28,760
3G					162	1.13	80	14,620
4	60	20	1,200		1,200	.25	80	24,000
roof	60	80	4,800		4,800	.15	80	57,600
floor	60	80		Perimeter =	280,		280(40)=	11,200
								203,560

Infiltration Heating Loss - Heating Plant

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
18K		1,015	18,290
	1 A	3,630	3,630
	1*A	22,220	22,220
	1 D	49,700	49,700
			93,840

EE. Building Number 47

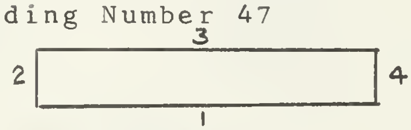

Figure XXXIX

BOQ

Exposure	Construction	Windows	Doors
1	W2	60 M	1 A, 1*A
2	W2	12 M	3 A
3	W2	60 M	3 A
4	W2	12 M	3 A
roof	R2	-	-
floor	F3	-	-

Heating Loss - BOQ

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	260	30	7,800	1,080	6,720	.21	80	112,900
1G					1,080	1.13	80	97,500
2	48	30	1,340	216	1,124	.21	80	18,900
2G					216	1.13	80	19,500
3	260	30	7,800	1,080	6,720	.21	80	112,900
3G					1,080	1.13	80	97,500
4	48	30	1,340	216	1,124	.21	80	18,900
4G					216	1.13	80	19,500
roof	260	48	12,480		12,480	.08	80	79,900
floor	260	48	12,480		12,480	.29	30	108,600
								686,100

Infiltration Heating Loss - BOQ

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
72 M		1,180	84,900
	1 A	3,630	3,630
	1*A	22,220	22,220
			110,750

FF. Building number 48

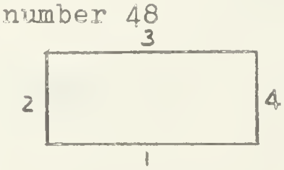

Figure XL

Officers' Club

Exposure	Construction	Windows	Doors
1	W4	2*0, 6 M	1*A, 1 A
2	W4	1*P	1 A
3	W4	2*0, 6 M	1 A
4	W4	1*P	2 A
roof	R3	-	-
floor	F4	-	-

Heating Loss - Officers' Club

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	145	12	1,740	144	1,576	.23	80	29,350
1G					144	1.13	80	13,010
2	80	12	960	48	912	.23	80	16,800
2G					48	1.13	80	4,340
3	145	12	1,740	144	1,576	.23	80	29,350
3G					144	1.13	80	13,010
4	80	12	960	48	912	.23	80	16,800
4G					48	1.13	80	4,340
roof	145	80	11,600		11,600	.07	80	65,000
floor	145	80	perimeter = 450,		450(40) =			18,000
								210,000

Infiltration Heating Loss - Officers' Club

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
2*O		380	760
1*P		443	886
6 M		1,180	7,080
	1*A	22,220	22,220
	2 A	3,630	7,260
			38,200

GG. Building number 49

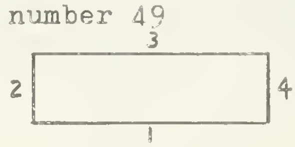

Figure XLI

Commissary

Exposure	Construction	Windows	Doors
1	W4	16 J	1*B
2	W4	-	-
3	W4	16 J	1 A, 1 C
4	W4	-	-
roof	R3	-	-
floor	F4	-	-

Heating Loss - Commissary

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	100	12	1,200	48	1,152	.23	80	21,200
1G					48	1.13	80	4,340
2	60	12	720		720	.23	80	13,250
3	100	12	1,200	48	1,152	.23	80	21,200
3G					48	1.13	80	4,340
4	60	12	720		720	.23	80	13,250
roof	100	60	6,000		6,000	.07	80	33,600
floor	100	60	perimeter = 320,		320(40) =			12,800
								123,980

Infiltration Heating Loss - Commissary

Exposures 1 and 2

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
16 J		505	8,080
	1*B	36,300	36,300
			44,380

HH. Building number 50

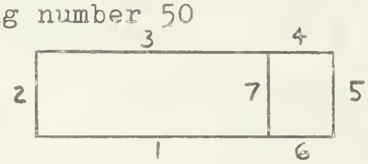

Figure XLII

Gymnasium and Lockers

Exposure	Construction	Windows	Doors
1	W4	40 K	1 A, 1*A
2	W4	-	2 A
3	W4	40 K	2 A
4	W4	4 J	-
5	W4	-	1 A
6	W4	4 J	-
7	W4	-	-
roof	R6, R1	-	-
floor	F4	-	-

Heating Loss - Gymnasium and Lockers

Exposure	Dimensions (ft)	(ft)	(sq-ft)	(sq-ft)	(sq-ft)	U	Temp. Diff. (F)	(Btu/hr)
1	140	22	3,080	360	2,720	.23	74	46,300
1G					360	1.13	74	30,100
2	80	22	1,760		1,760	.23	74	30,000
3	140	22	3,080	360	2,720	.23	74	46,300
3G					360	1.13	74	30,100
4	20	10	200	12	188	.23	84	3,630
4G					12	1.13	84	1,140
5	80	10	800		800	.23	84	15,460
6	20	10	200		188	.23	84	3,630
6G					12	1.13	84	1,140
7	80	12	960		960	.23	74	16,350
roof	140	80	11,200		11,200	.18	74	149,100
roof	20	80	1,600		1,600	.15	84	20,200
floor	160	80	perimeter = 480,		480(40) =			19,200
								412,650

Infiltration Heating Loss - Gymnasium and Lockers

Exposures 1, 2 and 6

Windows	Doors	Unit Infiltration (Btu/hr)	Infiltration Loss (Btu/hr)
40 K		1,015	40,600
4 J		505	2,020
	3 A	3,630	10,890
	1*A	22,220	22,220
			75,730 (74/80)
			= 70,100

II. Building number 51

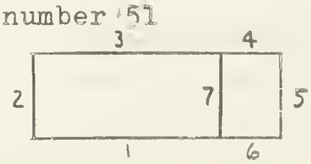

Figure XLIII

Service Station

Service Station

Exposure	Construction	Windows	Doors
1	W1	-	3 C
2	W1	-	
3	W1	-	
4	W1	2 J	
5	W1	*0	2 A
6	W1	*0	1*A
7	W1	-	-
roof	R1, R2	-	-
floor	F4	-	-

Heating Loss - Service Station

Exposure	Dimensions (ft)	(ft)	Gross Area (sq-ft)	Glass Area (sq-ft)	Net Area (sq-ft)	U	Temp. Diff. (F)	Heat Load (Btu/hr)
1	40	10	400	60	360	.29	74	7,720
1G					60	1.13	74	5,020
2	20	10	200		200	.29	74	4,290
3	40	10	400		400	.29	74	8,580
4	20	10	200	6	194	.29	80	4,500
4G					6	1.13	80	540
5	20	10	200	36	164	.29	80	3,810
5G					36	1.13	80	3,260
6	20	10	200	36	164	.29	80	3,810
6G					36	1.13	80	3,260
roof	40	20	800		800	.15	74	8,290
roof	20	20	400		400	.08	80	2,560
floor	60	20	perimeter = 160,		160(40) =			7,400
								63,040

Infiltration Heating Loss - Service Station

Infiltration is calculated based on two air changes/hour

Q(Btu/hr) = (volume)(Density air)(specific heat of air)(temp. diff.)
(air changes/hour)

Q = (12,000 cu-ft)(.080 lb mass/cu-ft)(.240 Btu/lb mass F)
(74 F)(2.0/hr)

Q = 34,100 Btu/hr

V. Design Domestic Hot Water Usage Quantities for Individual Buildings

Table 19 Domestic Hot Water Usage

Building Number	Population (persons)	Personnel Water Usage (gal/day)	Slop Sink Water Usage (gal/day)	Other Water Usage (gal/day)
1	300	600	30	800
2	50	100	30	600
3	10	20	10	20
4	100	200	30	-
5	200	400	60	200
6	200	400	100	200
7	40	80	20	-
8	100	200	60	-
10	20	1,000	30	-
11	20	40	30	-
12	20	40	30	-
20	20	1,200	60	200
21	300	600	90	-
22	100	200	30	-
23	100	200	30	-
24	100	200	60	-
25	175	8,750	120	-
26	175	8,750	120	-
27	175	8,750	120	-
28	175	8,750	120	-
29	175	8,750	120	-
30	175	8,750	120	-
31	175	8,750	120	-
32	175	8,750	120	-
33	100	200	150	8,000
34	10	40	60	1,000
35	6	20	30	450
36	20	40	30	10,000
37	10	400	30	-
38	20	70	30	100

Building Number	Population (persons)	Personnel Water Usage (gal/day)	Slop Sink Water Usage (gal/day)	Other Water Usage (gal/day)
39	300	600	60	-
40	300	600	60	-
41	300	600	60	-
42	100	200	60	-
43	90	360	30	100
44	150	300	30	100
46	10	40	30	30
47	200	6,000	120	2,000
48	10	40	60	800
49	20	40	60	100
50	100	3,000	60	-
51	4	20	30	100

VI. Design Domestic Hot Water Heating Load for Individual Buildings

Table 20 Domestic Hot Water Heating Load

Building Number	Gals HW per day	Heating Capacity Ratio	4 sq-ft EDR/100 F Temp. Rise	240 Btu/ sq-ft EDR	Heating Load Btu/hr
1	630	1/6	4	240	101,000
	800	1/10	4	240	76,800
2	130	1/6	4	240	20,800
	600	1/7	4	240	82,400
3	50	1/6	4	240	8,000
4	230	1/6	4	240	36,800
5	460	1/6	4	240	73,600
	200	1/8	4	240	24,000
6	500	1/6	4	240	80,000
	200	1/8	4	240	24,000
7	100	1/6	4	240	16,000
8	260	1/6	4	240	41,600
10	1,030	1/7	4	240	141,300
11	70	1/8	4	240	8,400
12	70	1/8	4	240	8,400
20	1,460	1/7	4	240	200,400
21	690	1/6	4	240	110,500
22	230	1/6	4	240	36,800
23	230	1/6	4	240	36,800
24	260	1/6	4	240	41,600
25	8,870	1/7	4	240	1,218,000
26	8,870	1/7	4	240	1,218,000
27	8,870	1/7	4	240	1,218,000
28	8,870	1/7	4	240	1,218,000
29	8,870	1/7	4	240	1,218,000
30	8,870	1/7	4	240	1,218,000
31	8,870	1/7	4	240	1,218,000
32	8,870	1/7	4	240	1,218,000
33	8,350	1/10	4	240	801,000
34	1,100	1/10	4	240	105,800

Building Number	Gals HW per day	Heating Capacity Ratio	4 sq-ft EDR/100 F Temp. Rise	240 Btu/ sq-ft EDR	Heating Load Btu/hr
35	500	1/10	4	240	48,000
36	10,090	1/10	4	240	969,000
37	430	1/7	4	240	59,000
38	200	1/6	4	240	32,000
39	660	1/6	4	240	105,000
40	660	1/6	4	240	105,700
41	660	1/6	4	240	105,700
42	360	1/6	4	240	57,600
43	490	1/8	4	240	58,700
44	430	1/8	4	240	51,600
46	100	1/8	4	240	12,000
47	8,120	1/7	4	240	1,114,000
48	900	1/10	4	240	86,400
49	200	1/8	4	240	24,000
50	3,060	1/7	4	240	420,000
57	150	1/8	4	240	18,000

VII. Design Process Steam Heating Load for Individual Buildings

A. Building number 20

Unit Description	Steam Consumption (lb/hr)	Steam Pressure (psig)
Bottle sterilizer, 24 bottle	24	40
Instrument sterilizer, 8x9x18 in.	27	40
Autoclave, 17.5 x 26 in.	32	40
Mattress disinfector 30x42x84 in.	42	40
Surgical sterilizer, 15x36 in.	54	40
	179	

Enthalpy steam at 40 psig = 1176 Btu/lb

Enthalpy fresh water at 40 = 8 Btu/lb

Enthalpy to generate steam = 1168 Btu/lb

(179 lb/hr)(1168 Btu/lb) = 209,000 Btu/hr

diversity factor = 60%

Heating load = .60(209,000 Btu/hr) = 125,400 Btu/hr

B. Building number 33

Unit Description	Steam Consumption (lb/hr)	Steam Pressure (psig)
8 vegetable kettles, 20 gal	640	10
4 steam tables	110	10
2 vegetable steamers	240	10
2 dishwashers	120	10
	1110	

Heating load = (.75 diversity factor)(1110 lb/hr)(1168 Btu/lb)

= 970,000 Btu/hr

C. Building number 36

Unit Description	Steam Consumption (lb/hr)	Steam Pressure (psig)
Tumbler, 40x94 in.	360	100
4 flatwork ironers	480	100
2 standard presses	210	100
2 shirt body presses	380	100
2 cuff and neckband presses	30	100
4 steam-electric irons	32	100
2 sleevers	24	100
	1516	

Heating load = (.90 diversity factor)(1516 lb/hr)(1168 Btu/lb)

= 1,594,000 Btu/hr

VIII Summary of Heating Loads

Table 21 Design Heating Load Summary by Building

Building Number	Heating Transmission Losses (Btu/hr)	Heating Infiltration Losses (Btu/hr)	Domestic HW Heat Load (Btu/hr)	Process Steam Load (Btu/hr)	Total Heat Load per Building (Btu/hr)
1	610,640	159,620	177,800	-	948,060
2	117,840	114,765	103,200	-	335,805
3	273,290	42,100	8,000	-	323,390
4	431,540	106,650	36,800	-	574,990
5	1,836,840	4,375,960	97,600	-	6,310,400
6	1,670,270	4,360,820	104,000	-	6,135,090
7	734,200	180,000	16,000	-	930,200
8	474,500	150,100	41,600	-	666,200
9	304,220	99,200	-	-	403,420
10	166,820	171,410	141,300	-	479,530
11	238,530	42,400	8,400	-	289,330
12	165,540	53,800	8,400	-	227,740
20	182,320	54,300	200,400	125,400	562,420
21	747,780	118,590	110,500	-	976,870
22	203,400	43,630	36,800	-	283,830
23	463,040	102,800	36,800	-	602,640
24	174,980	44,380	41,600	-	260,960

Building Number	Heating Transmission Losses (Btu/hr)	Heating Infiltration Losses (Btu/hr)	Domestic HW Heat Load (Btu/hr)	Process Steam Load (Btu/hr)	Total Heat Load per Building (Btu/hr)
25	501,680	128,060	1,218,000	-	1,847,740
26	501,680	128,060	1,218,000	-	1,847,740
27	501,680	128,060	1,218,000	-	1,847,740
28	501,680	128,060	1,218,000	-	1,847,740
29	501,680	128,060	1,218,000	-	1,847,740
30	501,680	128,060	1,218,000	-	1,847,740
31	501,680	128,060	1,218,000	-	1,847,740
32	501,680	128,060	1,218,000	-	1,847,740
33	461,080	97,610	801,000	970,000	2,329,690
34	246,720	38,570	105,800	-	391,090
35	169,340	37,610	48,000	-	254,950
36	210,800	48,650	969,000	1,594,000	2,822,450
37	112,880	15,810	59,000	-	187,690
38	151,400	37,010	32,000	-	220,410
39	371,750	89,910	105,700	-	567,360
40	371,750	89,910	105,700	-	567,360
41	371,750	89,910	105,700	-	567,360
42	230,440	65,000	57,600	-	353,040
43	313,990	318,000	58,700	-	690,690
44	236,620	71,300	51,600	-	359,520
45	187,160	37,900	-	-	225,060
46	203,560	93,840	12,000	-	309,400
47	686,100	110,750	1,114,000	-	1,910,850
48	210,000	38,200	86,400	-	334,600
49	123,980	44,380	24,000	-	192,360
50	412,650	70,100	420,000	-	902,750
51	63,040	34,100	18,000	-	115,140
Total	17,944,200	12,673,565	15,087,400	2,689,400	48,394,565

APPENDIX B

Calculations for Heating System Designs

I. Calculations for Heat Lost from Buried Pipes

The rate of heat loss from a buried pipe depends on a number of physical variables. In order to perform calculations based on laws of heat transfer it is necessary to determine or assume values for several of these variables.

The conductivity of the soil depends primarily on the type of soil, its density, its moisture content and whether or not it is in a frozen condition. The coast of Maine under consideration is from 20 to 30 feet above sea level and has a relatively thin overlay of sandy soil. Soil density averages 110 lb/cu-ft and moisture conditions during winter months in unfrozen soil will approach 20 percent. The design winter thermal conductivity for the soil is estimated to be 16.0 Btu/hr sq-ft F/in. The American Gilsulate Company publishes a technical data manual for their buried pipe insulation giving values of heat loss from buried pipe based on their recommended thickness of insulation, a ground conductivity of 12.0 Btu/hr sq-ft F/in., and a ground temperature averaging between 50 and 70 F. Heat loss results are tabulated by pipe size and fluid temperature for recommended thickness and type of insulation.

Actual conditions for this evaluation vary with respect to the conditions for which the available Gilsulate data were calculated.[1] Since the heat loss varies directly as the temperature difference between the fluid in the pipe and the soil and as the thermal conductivity of the soil, all other things being equal, it will be possible to construct an accurate table based on the conditions of this study

[illegible]

by merely performing a minimum number of calculations sufficient to establish the relationship between the original and the new table. The technical data assumes a value of soil conductivity of 1.0 Btu/hr sq-ft F/ft and a soil temperature averaging between 50 and 70 F whereas this study has a soil conductivity 33 percent larger and a soil temperature of 32 F. Both of these differences would tend to increase the pipe heat losses. Sample calculations for type "B" Gilsulate in the temperature range 220 to 390 F indicate an increase of 10 to 16 percent over published data. Results for buried pipe heat losses for this evaluation are presented in Table 22.

Table 22 Heat Loss Per Lineal Foot of Buried Pipe (Btu/hr/ft)

Pipe Diameter (inches)	Insulation Thickness (inches)	Temperature (F) 220	300	370	390
1	4	29	45	60	70
$1\frac{1}{4}$	4	31	49	64	75
$1\frac{1}{2}$	4	34	54	68	80
2	4	39	65	78	92
$2\frac{1}{2}$	4	42	70	85	99
3	4	46	75	94	108
$3\frac{1}{2}$	4	48	79	99	114
4	4	50	82	105	120
5	5	50	82	105	120
6	5	56	92	120	140
8	6	60	99	133	150
10	8	60	96	130	146

Values are for winter design soil conditions

Density = 110 lb/cu-ft

Moisture = 20 percent by weight (saturated soil)

Thermal conductivity = 16 Btu/hr sq-ft F/in.

Soil temperature = 32 F unfrozen

Pipe centerline burial is a minimum of 24 in. below ground level.

Calculations were based on the source-sink method for heat loss from buried pipes and figured with the aid of nomograph solutions in the Gilsulate Technical Data Manual, American Gilsonite Company, Salt Lake City, Utah.

II. Calculations for the Steam Distribution System

The steam piping from A (the central heating plant) to building 22 is designed for a total pressure drop of 50 psi. Since the steam generation pressure is 150 psig, this will provide the required 100 psig steam at the laundry building for use as process steam.

No steam piping smaller than 2 inch or condensate piping smaller than 1 inch is employed in the design.

Calculations are performed in the following sequence with sample calculations tabulated for the supply main pipe sections leading to each building group. Following the calculations, steam pipe sizes, pressures and condensate pipe sizes are listed for the pipe sections.

Tabular Row	Description of Calculation
(1)	Distance in equivalent feet of pipe from the central heating plant to the pipe section midpoint. (2,040 equiv. ft)
(2)	Pressure drop in psi for each section of pipe. (50 psi)(2,040 equiv. ft)/(8,196 equiv. ft) = (12.5 psi)
(3)	Pressure in psig at the midpoint of the pipe section (150 psig) - (12.5 psi) = (137.5 psig)
(4)	Pressure loss in oz/sq-in within the pipe section. $\frac{(16\text{oz/lb})(50\text{psi})(4{,}080 \text{ equiv. ft})}{(8{,}196 \text{ equiv. ft})}$ = (398 oz/sq-in)
(5)	Length of the pipe section in equivalent feet (4,080 equiv. ft)

(6) Main sizing is based on the formula

$$W = 87\sqrt{\frac{Pd\ D^5}{1 + (\frac{3.6}{D})L}}$$

W = steam flow rate (lb/min)

P = pressure drop (psi)

D = pipe inside diameter (in.)

L = pipe length (equiv. ft)

d = density of steam (lb/cu-ft)

This formula is divided into four columns, each containing either P, D, L or d to facilitate piping design.

Column 1 represents $87\sqrt{\frac{P}{100}}$

$$87\sqrt{P/100} = 87\sqrt{24.9/100} = 43.4$$

(7) Column 3 representing $\sqrt{d}$

$$\sqrt{d} = .579$$

(8) Column 4 represents $\sqrt{100/L}$

$$\sqrt{100/L} = \sqrt{100/4,080} = .1566$$

(9) Heat load carried within the pipe section expressed in mbtu/hr and includes factors of 1.30 and 1.15 times the building design heating to allow for future expansion and heat transmission losses. The 15 percent heat transmission loss allowance is checked at the end of the pipe design.

(10) Pounds of condensate per hour within the pipe section under design load conditions.

(43,100 MBtu/hr)1000/(960 Btu/lb) = (44,900 lb/hr)

(11) Pounds of condensate per minute within the pipe section under design load conditions.

(44,900 lb/hr)(hr/60 min) = (749 lb/min)

(12) Column 2 representing W divided by columns 1, 2 and 4.

Col. 2 = (749 lb/min)/(43.4)(.579)(.1566) = 190.4

(13) The tentative pipe size is selected from the expression

$$\text{Col. } 2 = \sqrt{\frac{D^5}{1 + \frac{3.6}{D}}}$$

A pipe size of 10 inches is selected. The 10 inch pipe is larger than necessary, however, the next smaller standard size of 8 inches is too small since it would result in an excessive pressure loss.

(14) Recalculate the value of column 2 based on the selected value of pipe size.

Col. 2 for a 10 inch pipe = 272.6

(15) Calculate column 1 for the selected pipe size.

Col. 1 = (749 lb/min)/(272.6)(.579)(.1566) = 30.4

(16) Calculate the pipe section pressure loss.

$$\text{Col. } 1 = 87 \sqrt{P/100}$$

$$p = 12.2 \text{ psi}$$

(17) Determine the pressure at the end point of the pipe section.

(150 psig)-(12.2 psi) = (137.8 psig)

(18) Determine the steam velocity from friction resistance charts in the ASHAE Guide.

Velocity = 4,300 fpm

The calculations presented above for rows (1) to (18) are presented in tabular form for each supply main pipe section on the following pages. Note that two successive pages are required to complete each steam supply main. Pipe sizes for the steam alternative are summarized in table 23.

	Pipe Sections for Group I Buildings	AB	BC	CD
(1)	Distance, plant to midpoint (equiv.ft)	199	946	1,708
(2)	Pressure drop plant to midpoint (psi)	1.7	7.8	14.1
(3)	Pressure at midpoint (psig)	148.3	142.2	135.9
(4)	Pressure loss in section (OZ/sq-in)	52.4	144	56.6
(5)	Length of pipe section (equiv. ft)	398	1,095	430
(6)	Column 1	15.78	26.5	16.39
(7)	Column 3	.599	.588	.576
(8)	Column 4	.501	.303	.482
(9)	MBtu/hr	28,800	26,300	25,600
(10)	lbs condensate/hr	30,000	27,400	26,700
(11)	lbs condensate/min	500	457	445
(12)	Column 2 = $\frac{\text{(lbs condensate/min)}}{\text{(col.1)(col.3)(col.4)}}$	105.8	96.8	97.6
(13)	Pipe size (in.)	6-	o-	6-

	Pipe Section	AB	BC	CD
(11)	lbs condensate/min	500	457	445
(14)	Column 2	71.8	71.8	71.8
(7)	Column 3	.599	.588	.576
(8)	Column 4	.501	.303	.482
(15)	Column 1 = $\frac{\text{(lbs condensate/min)}}{\text{(col.2)(col.3)(col.4)}}$	23.2	35.7	22.3
(16)	Pressure loss (psi)	7.1	16.9	6.6
(17)	Pressure at pipe section end point (psig)	142.9	126.0	119.4
(18)	Velocity in pipe section (fpm)	7,300	7,300	7,500

	DE	EF	FG	GH	HI	IJ	J-12
(1)	2,431	3,118	3,481	4,008	4,828	5,603	5,999
(2)	20.0	24.7	28.7	33.0	39.8	46.1	49.4
(3)	130.0	125.3	121.3	117.0	110.2	103.9	100.6
(4)	152	50.1	42.8	96.2	120	84.3	20.2
(5)	1,015	380	325	730	910	640	153
(6)	36.8	15.4	14.24	21.35	23.9	19.98	9.79
(7)	.565	.577	.549	.542	.526	.514	.508
(8)	.314	.514	.556	.370	.332	.396	.810
(9)	24,000	21,800	21,300	19,300	10,200	773	262
(10)	25,000	22,700	22,200	20,100	10,600	805	273
(11)	417	379	370	335	177	13.4	4.55
(12)	87.5	83.1	85.0	78.2	42.3	3.30	1.13
(13)	6-	6-	6-	6-	5+	2+	2+

	DE	EF	FG	GH	HI	IJ	J-12
(11)	417	379	370	335	177	13.4	4.55
(14)	71.8	71.8	71.8	71.8	43.7	3.71	3.71
(7)	.565	.577	.549	.542	.526	.514	.508
(8)	.314	.514	.556	.370	.332	.396	.810
(15)	32.7	17.8	16.9	23.2	23.2	17.85	2.98
(16)	14.1	4.2	3.8	7.1	7.1	4.2	.1
(17)	105.3	101.1	97.3	90.2	83.1	78.9	78.8
(18)	7,500	6,900	7,000	6,900	7,200	3,200	1,000

	Pipe Sections for Group II Buildings	AB	BC	CE
(1)	Distance, plant to midpoint (equiv.ft)	2,040	4,522	5,184
(2)	Pressure drop plant to midpoint (psi)	12.5	27.6	31.6
(3)	Pressure at midpoint (psig)	137.5	122.4	118.4
(4)	Pressure loss in section (OZ/sq-in)	398	86.3	42.9
(5)	Length of pipe section (equiv. ft)	4,080	884	440
(6)	Column 1	43.4	20.2	14.25
(7)	Column 3	.579	.551	.543
(8)	Column 4	.1566	.336	.477
(9)	MBtu/hr	43,100	42,200	38,600
(10)	lbs condensate/hr	44,900	44,000	40,300
(11)	lbs condensate/min	749	734	670
(12)	Column 2 = $\frac{\text{(lbs condensate/min)}}{\text{(col.1)(col.3)(col.4)}}$	190.4	196.0	181.5
(13)	Pipe size (in)	10+	8-	8-

	Pipe Section	AB	BC	CE
(11)	lbs condensate/min	749	734	670
(14)	Column 2	272.6	149.4	149.4
(7)	Column 3	.579	.551	.543
(8)	Column 4	.1566	.336	.477
(15)	Column 1 = $\frac{\text{(lbs condensate/min)}}{\text{(col.2)(col.3)(col.4)}}$	30.4	26.5	17.3
(16)	Pressure loss (psi)	12.2	9.3	4.0
(17)	Pressure at pipe section and point (psig)	137.8	128.5	124.5
(18)	Velocity in pipe section (fpm)	4,300	7,300	6,100

	EF	FG	GH	HI	IJ	JK	KL	LM
(1)	5,526	5,879	6,348	6,743	7,052	7,335	7,748	8,112
(2)	33.7	35.9	38.7	41.2	43.1	44.8	47.2	49.5
(3)	116.3	114.1	111.3	108.8	106.9	105.2	102.8	100.5
(4)	23.9	44.9	46.8	30.3	30.2	25.1	55.2	16.3
(5)	245	460	479	310	309	257	565	167
(6)	10.64	14.59	14.89	11.98	11.85	10.91	16.19	8.79
(7)	.539	.534	.529	.524	.520	.516	.512	.507
(8)	.639	.467	.458	.568	.569	.624	.421	.775
(9)	31,000	20,000	8,920	7,190	6,340	1,275	596	326
(10)	32,300	20,800	9,300	7,500	6,600	1,330	622	352
(11)	538	347	155	125	110	22.2	10.4	5.9
(12)	146.9	95.4	42.9	35.2	31.4	6.32	2.98	1.71
(13)	8+	6-	5+	4-	4-	$2\frac{1}{2}$-	2+	2+

	EF	FG	GH	HI	IJ	JK	KL	LM
(11)	538	347	155	125	110	22.2	10.4	5.9
(14)	149.4	71.8	43.7	23.6	23.6	6.11	3.71	3.71
(7)	.539	.534	.529	.524	.520	.516	.512	.507
(8)	.639	.467	.458	.568	.569	.624	.421	.775
(15)	10.5	19.4	14.6	17.8	15.8	11.3	13.0	4.04
(16)	1.5	5.0	2.8	4.2	3.3	1.7	2.2	.2
(17)	123.0	118.0	115.2	111.0	107.7	106.0	103.8	103.6
(18)	5,300	6,100	3,900	5,400	4,600	2,500	1,800	1,000

Table 23 Pipe Sizes for the Steam Alternative

Pipe Section Building Group I	Pipe Loading lb/hr	Straight Pipe Length ft	Steam Pipe Size in.	Section Starting Pressure psig	Section Ending Pressure psig	Condensate Pipe Size in.
AB	30,000	340	6	150.0	142.9	3
BC	27,400	960	6	142.9	126.0	3
CD	26,700	370	6	126.0	119.4	3
DE	25,000	890	6	119.4	105.3	3
EF	22,700	335	6	105.3	101.1	3
FG	22,200	280	6	101.1	97.3	3
GH	20,100	640	6	97.3	90.2	3
HI	10,600	820	5	90.2	83.1	2½
IJ	805	588	2	83.1	78.9	1
J-12	273	135	2	78.9	78.8	1
BL	2,600	885	3	142.9	138.1	1½
LM	1,460	390	2½	138.1	136.0	1½
MN	910	380	2	136.0	133.8	1
N-45	270	265	2	133.8	133.6	1
N-44	432	30	2	133.8	133.7	1
N-42	423	30	2	136.0	135.9	1
L-43	829	30	2	138.1	137.9	1
C-10	575	60	2	126.0	125.8	1
DO	1,290	83	2½	119.4	119.1	1
O-8	800	70	2	119.1	118.7	1
O-9	490	1,205	2	119.1	116.4	1
E-4	690	215	2	105.3	104.5	1
E-7	1,120	70	2	105.3	104.7	1
F-3	390	30	2	101.1	101.0	1
G-1	1,140	298	2	97.3	95.0	1
G-2	400	260	2	97.3	96.9	1
H-6	7,340	40	3½	90.2	89.2	2
I-5	6,880	40	3½	83.1	82.1	2
J-11	315	40	2	78.9	78.8	1

Pipe Section Building Group I	Pipe Loading lb/hr	Straight Pipe Length ft	Steam Pipe Size in.	Section Starting Pressure psig	Section Ending Pressure psig	Condensate Pipe Size in.
AB	44,900	3,400	10	150.0	137.8	4
BC	44,000	760	8	137.8	128.5	4
CE	40,300	204	8	128.5	124.5	4
EF	32,300	190	8	124.5	123.0	3½
FG	20,800	410	6	123.0	118.0	3
GH	9,300	440	5	118.0	115.2	2½
HI	7,500	280	4	115.2	111.0	2
IJ	6,600	280	4	111.0	107.7	2
JK	1,330	240	2½	107.7	106.0	1½
KL	622	540	2	106.0	103.8	1
L-22	352	150	2	103.8	103.6	1
B-34	470	88	2	137.8	137.7	1
B-35	300	404	2	137.8	137.7	1
C-33	2,790	112	3	128.5	128.0	1½
FS	4,430	65	3	123.0	122.3	2
S-31	2,215	65	2	122.3	121.0	1½
S-32	2,215	65	2	122.3	121.0	1½
FT	4,430	220	3	123.0	120.8	2
T-27	2,215	65	2	120.8	119.5	1½
T-28	2,215	65	2	120.8	119.5	1½
GU	4,430	65	3	118.0	117.3	2
U-29	2,215	65	2	117.3	116.0	1½
U-30	2,215	65	2	117.3	116.0	1½
GV	4,430	220	3	118.0	115.8	2
V-25	2,215	65	2	115.8	114.5	1½
V-26	2,215	65	2	115.8	114.5	1½
H-23	722	116	2	115.2	114.8	1¼
H-41	680	90	2	115.2	115.0	1¼
I-40	680	90	2	111.0	110.8	1¼
J-39	680	90	2	107.7	107.5	1¼
J-36	3,380	340	3	107.7	105.3	1½

Pipe Section Building Group I	Pipe Loading lb/hr	Straight Pipe Length ft	Steam Pipe Size in.	Section Starting Pressure psig	Section Ending Pressure psig	Condensate Pipe Size in.
KW	543	114	2	106.0	105.8	1
W-24	313	70	2	105.8	105.7	1
W-49	230	25	2	105.8	105.7	1
L-51	138	154	2	103.8	103.7	1
EN	7,930	920	5	124.5	120.4	2
NO	7,410	390	4	120.4	116.0	2
OP	6,000	260	4	116.0	113.8	2
PQ	2,690	250	3	113.8	111.5	1½
Q-21	1,520	1,300	2½	111.5	102.4	1½
N-48	400	444	2	120.4	119.9	1¼
O-50	1,080	60	2	116.0	115.5	1¼
P-38	264	124	2	113.8	113.7	1¼
P-47	2,300	338	2	113.8	101.6	1½
Q-20	674	162	2	111.5	111.0	1¼
Q-37	226	88	2	102.4	102.3	1¼

A. Buried steam pipe heat losses

Table 24 Steam Piping Heat Losses

Pipe Size in.	Length ft	Average Temperature F	Average Heat Loss Btu/hr/ft	Total Heat Loss Btu/hr
10	3,400	363	127	432,000
8	1,190	354	125	149,000
6	4,225	350	112	477,000
5	2,180	338	95	207,000
4	1,210	347	97	117,000
3½	80	328	87	7,000
3	2,157	355	90	194,000
2½	2,013	344	79	159,000
2	7,423	344	73	542,000
				2,284,000 Btu/hr

B. Trapping and condensate piping heat losses

The estimated return temperature of the condensate at the heating plant is 180 F.

Enthalpy of saturated water at 5.3 psig = 196.16 Btu/lb

Enthalpy of saturated water at 180 F = 147.92 Btu/lb

Condensate heat losses = (rate of flow lb/hr)(enthalpy diff.)
= (74,900 lb/hr)(196.16 - 147.92) Btu/lb
= 3,610,000 Btu/hr

C. Steam trap and pumping losses

At condensate temperature 227.96 F the corresponding properties are:

Pressure = 20 psia = 5.3 psig

Density = 59.4 lb/cu-ft

Specific heat = 1.00 Btu/lb F

Enthalpy saturated liquid = 196.16 Btu/lb

Heat of vaporization = 960.1 Btu/lb

Enthalpy saturated steam = 1156.3 Btu/lb

For steam which uses only latent heat as useful heat in a heat exchanger there are losses of heat during the trapping process. The condensate temperature is reduced as it collects awaiting to be returned by pump to the heating plant.

Heat lost in trapping = (enthalpy of condensate at 227.96 F) - (enthalpy of condensate at 212 F)
= (196.16 Btu/lb)-(180.07 Btu/lb)
= 16.09 Btu/lb

% condensate re-evaporated = (enthalpy of condensate at 227.96 F)-(enthalpy of condensate at 212 F) 100 ÷ (heat of vaporization at 1 atmosphere)

$$= \frac{(196.16\ \text{Btu/lb})-180.07\ \text{Btu/lb})(100)}{(970.3\ \text{Btu/lb})}$$

= 1.655 %

% condensate remaining = 98.345 %

Heat loss due to trapping flash steam makeup

Heat lost = .01655(74,900 lb/hr)(1 Btu/lb F)(180-50)F

Heat lost = 161,000 Btu/hr

D. Total distribution system heat losses

Table 25 Summary of Steam Distribution System Heat Losses

Buried steam piping heat losses	2,284,000 Btu/hr
Steam side eqipment room heat losses	350,000
Trapping and condensate piping heat losses	3,610,000
Trapping flash steam makeup losses to 180 F	161,000
Total steam distribution system heat losses	6,405,000 Btu/hr

Percent of heat losses in the steam distribution system

% losses = (6,405 MBtu/hr)100/(69,300 MBtu/hr) = 9.25%

Corrected steam flow rates based on actual transmission heat losses

Building heat load	48.4 million Btu/hr
Expansion allowance	14.5
Losses in transmission	6.4
Supply heat load	69.3 million Btu/hr

Supply steam = (69,300,000 Btu/hr)/(960 Btu/lb)
= 72,250 lb/hr from and at 212 F

E. Heat capacity of the steam piping

Table 26 Heat Capacity of the Steam Supply Piping

Pipe Size in.	Steam Piping Volume cu-ft	Average Supply Pressure psig	Enthalpy Sat. Vapor Supply Btu/lb	Enthalpy Sat. Liquid Discharge Btu/lb	Usable Heat Btu/lb
10	1,860	144	1,195	196	999
8	413	128	1,193	196	997
6	846	120	1,192	196	996
5	303	100	1,190	196	994
4	108	114	1,192	196	996
3½	6	86	1,187	196	991
3	111	128	1,193	196	997
2½	67	110	1,191	196	995
2	173	110	1,191	196	995

Pipe Size in.	Spec. Vol. At Supply Pressure cu-ft/lb	Density At Supply Pressure lb/cu-ft	Usable Heat Btu/cu-ft	Heat Capacity of Steam Supply Pipe Btu
10	2.85	.351	351	653,000
8	3.16	.316	315	130,000
6	3.33	.300	299	253,000
5	3.89	.257	256	78,000
4	3.48	.288	287	31,000
$3\frac{1}{2}$	4.42	.226	224	1,000
3	3.16	.316	315	35,000
$2\frac{1}{2}$	3.62	.276	275	18,000
2	3.62¢	.276	275	48,000
				1,247,000

Heat capacity is calculated based on the discharge steam and condensate pressure of 53 psig and the average supply pressure for each size pipe.

F. Calculations for trapping a steam main

The condensate formed due to warmup for the 10" steam supply main is:

lbs condensate = (heat lost)/(heat of vaporization)

= (total weight)(specific heat)(temp diff)/(860 Btu/lb)

= (3,400 ft)(40.5 lb/ft)(.114 Btu/lb F)(366-32 F)/860

= 6,100 lbs

Assuming one hour is allowed for initial warmup, the steam trap size is figured as follows:

lbs/hr condensate = (lbs condensate)(60 min/hr)/(warm up time)

= (6,100 lbs)(60 min/hr)/(60 min)

= 6,100 lbs/hr

Assuming a safety factor of 3 to 1 gives lbs/hr condensate = 6,100 (3)=18,300 lb/hr

Therefore, with a pressure differential of 100 psi and a flow rate of 18,300 lb/hr a trap is selected from a trap catalog.[2] The trap, complete with check valve and strainer, will cost $110.00

G. Calculations for selecting condensate receivers

The 3,400 ft section of condensate return pipe from group II buildings will account for the major portion of the condensate return piping pressure drop. This drop is checked prior to selecting pipe sizes and receiver pumping pressures. Results are presented in Table 27.

Table 27 Condensate Return Piping Friction Loss

Pipe Size in.	Friction Loss psi/100 ft	Total Head Loss psi
3	2.4	98.1
3½	1.1	45.0
4	.58	23.7
5	.18	7.4

Building 33 has a design load of 2,790 lb condensate/hr or a building capacity of approximately 15,000 sq-ft EDR. Therefore, a condensate receiver with a pump capacity of 22½ gpm is selected. The pump selected will operate at 40 psig at the outlet to provide the pressure differential required to introduce the condensate into the return system and overcome frictional resistance in the return piping.

The condensate receivers and pumps are listed in Table 28.

Table 28 Condensate Pump and Receiver Sizing and Cost

Building Number	Pump Pressure psig	Unit Capacity gpm	Motor Size HP	Cost[19] $
1	20	6,000	1/3	388
2	20	2,000	1/3	388
3	20	2,000	1/3	388
4	20	4,000	1/3	388
5	20	25,000	3/4	691
6	20	25,000	3/4	691
7	20	6,000	1/3	388
8	20	4,000	1/3	388
9	20	2,000	1/3	388
10	15	4,000	1/3	388
11	20	2,000	1/3	388
12	20	2,000	1/3	388
20	40	4,000	1	459
21	40	8,000	1	459
22	40	2,000	1	459
23	40	4,000	1	459
24	40	2,000	1	459
25	40	10,000	1	668
26	40	10,000	1	668
27	40	10,000	1	668
28	40	10,000	1	668
29	40	10,000	1	668
30	40	10,000	1	668
31	40	10,000	1	668
32	40	10,000	1	668
33	40	15,000	$1\frac{1}{2}$	701
34	40	2,000	1	459
35	40	2,000	1	459
36	40	15,000	$1\frac{1}{2}$	701
37	40	2,000	1	459
38	40	2,000	1	459

Building Number	Pump Pressure psig	Unit Capacity gpm	Motor Size HP	Cost $
39	40	4,000	1	459
40	40	4,000	1	459
41	40	4,000	1	459
42	15	2,000	1/3	388
43	15	4,000	1/3	388
44	15	2,000	1/3	388
45	15	2,000	1/3	388
46	10	2,000	1/3	388
47	40	10,000	1	668
48	40	2,000	1	459
49	40	2,000	1	459
50	40	6,000	1	459
51	40	2,000	1	459
10 in. main	40	30,000	2	942
		Total cost *		$22,902

* The average cost per utility room for condensate pump and receiver is $500.

III. Calculations for the HTW Distribution System

The HTW piping circuit from A (the central heating plant) to building 22 is the longest and heaviliest loaded circuit. Select this circuit as the primary circuit. Perform calculations for pipe sizing, HTW velocity, frictional resistance, line temperature drop and line pressure drop.

The HTW primary circuit distribution piping is designed for a maximum head loss of 166 ft of water exclusive of central plant losses. Section AB will be based on a frictional resistance of 0.143 in. of water/ft of pipe and the remaining pipe sections will be based on an average frictional resistance of 0.083 in. of water/ft of pipe.

Once the primary circuit has been designed then all additional circuits, branches, and individual building services are designed to give balanced flow with respect to the primary circuit.

Calculations are performed in the following sequence with a sample calculation of pipe section AB of building group II being presented.

Tabular Column	Description of Calculation
(1)	Pipe section as designated on Figure III or IV.
(2)	Design heating load for individual buildings summarized for the pipe section by adding the appropriate loads from Table 2 that are handled by the pipe section being designed.
(3)	Each pipe section which ultimately serves more than a single building has its heating load value in column 2 increased by 30 percent to allow for future expansion. (27,239 MBtu/hr)(1.30) = (35,400 MBtu/hr)
(4)	Allow 10 percent heat loss to compensate for pipe transmission heat losses. This assumption was rechecked for the completed design and found to be realistic for the long circuits and type of insulation employed. (35,400 MBtu/hr)(1.10) = (38,940 MBtu/hr)
(5)	Calculate the heating load in each pipe section by dividing column (4) by the design temperature drop. (38,940 MBtu/hr)/(170 F) = (229 MBtu/hr/F) Note, (1 MBtu/hr/F) = (1 Mlb water/hr)

(6) With the heating load (MBtu/hr/F) or (Mlb water/hr) enter the chart of curves based on Fanning's formula and select a suitable pipe size to maintain the desired value of frictional resistance. A 6 inch pipe is selected.

(7) The actual velocity from the curves for the pipe diameter selected and the heating load.

Velocity = 5.5 fps.

(8) The actual frictional resistance for the pipe selected equals 0.143 in. of water/ft of pipe.

(9) Scale the parallel supply and return piping combined run from the building development plans, double this figure, and add the extra pipe length required for expansion loops to get the total straight pipe for each pipe section.

Length AB = 2(scaled length) + added length
= 2(3,020 ft) + (10 loops)(4 runouts/loop) (19 ft/runout)
= 6,800 ft. of straight pipe

(10) Calculate the equivalent straight pipe length by assuming an appropriate pipe size and for that pipe section adding all fitting allowances to the straight pipe length.

Straight pipe AB	6,800 ft
80-90 deg. long sweep-8 in. @ 16.1 ft. ea.	1,290 ft
2-45 deg. welding elbows-8 in. @ 5.7 ft. ea.	11 ft
6-90 deg. welding elbows-8 in. @ 8.7 ft. ea.	52 ft
Equivalent straight pipe length =	8,153 ft

(11) Calculate the frictional resistance in each pipe section by multiplying column (8) and column (10)

Fric. Res. = (0.143 in. of water/ft of pipe) (8,153 ft of pipe)
= 1,168 in. water

(12) Note the letter designation of each pipe section's starting end.

(13) Corresponding to the letter in column (12) calculate the total design frictional resistance in inches of water by adding the sectional resistances from column (11) successively from the end of the circuit. For the primary circuit this value represents the pressure drop which must be used to balance all remaining pipe sections. For example, when balancing the branch E to building 21. Point E has an index value of 477 in. water. Building 21 utility room is allowed a minimum of 300 in. of water. Therefore, the piping from E to building 21 is allowed the difference or 477 - 300 = 177 in.

(177 in. water)/(6,910 ft pipe) =

(0.026 in. water/ft of pipe)

Then the pipes from E to building 21 are designed to balance with the primary circuit. If the circuit cannot be balanced without using unreasonably small pipes, it will be necessary to select a pipe size and compensate for the additional required frictional resistance when initially balancing the system by means of balancing cocks located after the utility room heat exchanger equipment.

(14) Determine from Table 22 the supply pipe transmission heat losses for the pipe size and fluid temperature in (Btu/hr/ft of pipe).

Section AB is 6 in. and contains HTW at 390 F, therefore the transmission heat loss will be (140 Btu/hr/ft).

(15) Calculate the temperature drop for the supply side of each pipe section only.

Temp. drop = (140 Btu/hr/ft)(3,400 ft)/(229,000 lbs water/hr)

= 2.07 F

(16) Calculate the temperature at the terminal end of each supply pipe section.

Temp. = 390 F - 2.07 F

= 387.9 F at point B

(17) Calculate the pressure drop due to the frictional resistance for the supply side of each section of piping.

$$\text{Pressure drop (psi)} = 4\ fLV^2\ (\text{density})/144\ D2g$$

Therefore pressure drop is proportional to density for purposes of correcting for fluid temperature. Since the pipe sizing chart was based on 300 F average water temperature, it is necessary to correct the pressure drop calculations when considering the supply side of the piping solely.

Pressure drop = (in. of water supply section head) (density at the average export temp. for the pipe section)/(12 in./ft) (144 sq-in/sq-ft)

= (584 in.)(54.09 lb/cu-ft)/(12)(144)

= 18.3 psi

(18) Calculate the pressure at the end of each pipe section for the supply side. Starting with 250 psig deduct the plant losses and then each section's losses successively.

Operating pressure	250.0 psig
Central heating plant losses	12.0 psi
30 ft of water at 300 F avg. temp.	
Pressure at point A	238.0 psig
Section AB building group II losses	18.3 psi
Pressure at point B, group II	219.7 psig

(19) Determine the saturation temperature corresponding to the pressure for each point as calculated for (18).

Pressure at point B	219.7 psig
Equivalent to	234.4 psia
Corresponding sat. temp.	395.4 F

The calculations presented above as columns (1) to (19) are presented in tabular form for each pipe section on the following pages.

Note that three successive pages are required to complete each pipe section's calculations and results.

(1) Group II Bldg. Pipe Section	(2) Design Bldg. Heat Load MBtu/hr	(3) 30 Percent Allowance for Main Expansion MBtu/hr	(4) 10 Percent Allowance System Losses MBtu/hr	(5) Heat Load mlbs Water/ hr	(6) Pipe Size in.	(7) HTW Vel. fps
AB	27,239	35,400	38,940	229	6	5.5
BC	26,593	34,550	38,000	224	6	5.3
CD	24,263	31,550	34,7000	204	6	4.8
DE	24,263	31,550	34,700	204	6	4.8
EF	19,167	24,900	27,400	161	6	3.8
FG	11,776	15,300	16,800	99	6	2.3
GH	4,385	5,700	6,270	37	4	1.8
HI	3,215	4,180	4,600	27	3½	1.8
IJ	2,648	3,440	3,780	22	3½	1.5
JK	852	1,108	1,220	7.1	2½	0.9
KL	399	519	570	3.4	2	1.3
L-22	284	-	312	1.9	1¼	1.0
Bldg. 22	-	-	-	-	-	-
EN	5,096	6,624	7,280	43	5	1.5
NO	4,761	6,189	6,800	40	4	2.0
OP	3,858	5,016	5,520	33	4	1.8
PQ	1,727	2,245	2,470	15	3	1.3
Q-21	977	1,270	1,400	8.3	2½	1.2
Bldg. 21	-	-	-	-	-	-
B-34	391	-	430	2.5	1	2.1
Bldg. 34	-	-	-	-	-	-
B-35	255	-	280	1.7	1¼	0.7
Bldg. 35	-	-	-	-	-	-
C-33	2,330	-	2,560	15.1	2½	2.7
Bldg. 33	-	-	-	-	-	-
FS	3,695	-	4,060	23.9	3	2.2
S-31, 32	1,848	-	2,030	12.0	2	2.5
Bldgs. 31, 32	-	-	-	-	-	-
FT	3,695	-	4,060	23.9	3	2.2
T-27, 28	1,848	-	2,030	12.0	2	2.5
Bldgs. 27, 28	-	-	-	-	-	-
GU	3,695	-	4,060	23.9	3	2.2

(1) Group II Bldg. Pipe Section	(8) Fric. Res. in. of water/ ft	(9) Straight Pipe Length ft	(10) Equiv. Straight Pipe Length ft	(11) Section Fric. Res. in. of water	(12) Section Starting Point Letter	(13) Circuit Fric. Res. in. of water
AB	.143	6,800	8,153	1,168	A	1,995
BC	.140	1,520	1,778	249	B	827
CD	.114	480	645	74	C	578
DE	.114	140	237	27	D	504
EF	.075	380	490	37	E	477
FG	.030	820	920	28	F	440
GH	.034	880	958	33	G	412
HI	.037	560	620	23	H	379
IJ	.026	560	618	16	I	356
JK	.018	480	514	9	J	340
KL	.014	1,080	1,130	16	K	331
L-22	.045	300	334	15	L	315
Bldg. 22	-	-	-	300	22	300
EN	.017	1,840	2,050	35	E	478
NO	.040	780	870	35	N	443
OP	.028	520	580	16	O	408
PQ	.028	500	560	16	P	392
Q-21	.023	2,600	2,850	66	Q	376
Bldg. 21	-	-	-	310	21	310
B-34	.230	176	210	48	B	828
Bldg. 34	-	-	-	780	34	780
B-35	.037	808	860	32	B	827
Bldg. 35	-	-	-	795	35	795
C-33	.072	224	258	19	C	579
Bldg. 33	-	-	-	560	33	560
FS	.066	130	165	11	F	438
S-31, 32	.135	130	165	22	S	427
Bldgs. 31, 32	-	-	-	405	31, 32	405
FT	.066	440	475	[illegible]	F	438
T-27, 28	.135	130	165	22	T	[illegible]
Bldgs. 27, 28	-	-	-	385	27, 28	385
GU	.066	130	165	11	G	413

(1) Group II Bldg. Pipe Section	(14) Supply Heat Losses Btu/hr/ft	(15) Supply Section Temp. Drop F	(16) Supply Section Ending Temp. F	(17) Supply Section Press. Drop psi	(18) Supply Section Ending Press. psig	(19) Corres. Sat. Temp. F
AB	140	2.07	387.9	18.3	219.7	395.4
BC	138	.47	387.5	3.9	215.8	393.9
CD	138	.16	387.3	1.1	214.7	393.5
DE	138	.05	387.2	.4	214.3	393.3
EF	138	.16	387.1	.6	213.7	393.1
FG	137	.57	386.5	.4	213.3	392.9
GH	117	1.39	385.1	.5	212.8	392.7
HI	111	1.15	384.0	.4	212.4	392.5
IJ	110	1.41	382.6	.3	212.1	392.4
JK	93	3.14	379.4	..1	212.0	392.4
KL	85	13.5	365.9	.3	211.7	392.3
L-22	61	4.82	361.1	.3	211.4	392.2
Bldg. 22	-	-	-	9.5	201.9	388 6
EN	118	2.52	386.7	.5	213.8	393.1
NO	116	1.13	385.6	.6	213.2	392.9
OP	116	.91	384.7	.2	213.0	392.8
PQ	104	1.73	382.9	.3	212.7	392.7
Q-21	93	14.59	368.3	1.0	211.7	392.3
Bldg. 21.	-	-	-	9.5	201.9	388.6
B-34	74	2.60	385.3	1.2	218.5	395.0
Bldg. 34	-	-	-	9.5	209.0	391.3
B-35	70	16.7	371.2	.5	219.2	395.2
Bldg. 35	-	-	-	9.5	209.7	391.6
C-33	97	.72	386.8	.3	215.5	393.8
Bldg. 33	-	-	-	9.5	206.0	390.2
FS	107	.29	386.8	.2	213.5	393.0
S-31, 32	92	.50	386.3	.3	213.2	392.9
Bldgs. 31, 32	-	-	-	9.5	203.7	389.2
FT	107	.99	386.1	.5	213.2	392.9
T-27, 28	92	.50	385.6	.3	212.9	392.7
Bldgs. 27, 28	-	-	-	9.5	203.4	389.1
GU	105	.29	386.2	.2	213.1	392.8

(1) Group II Bldg. Pipe Section	(2) Design Bldg. Heat Load MBtu/hr	(3) 30 Percent Allowance for Main Expansion MBtu/hr	(4) 10 Percent Allowance System Losses MBtu/hr	(5) Heat Load mlbs Water/ hr	(6) Pipe Size in	(7) HTW Vel. fps
U-29, 30	1,848	-	2,030	12.0	2	2.5
Bldgs. 29, 30	-	-	-	-	-	-
GV	3,695	-	4,060	23.9	3	2.2
V-25, 26	1,848	-	2,030	12.0	2	2.5
Bldgs. 25, 26	-	-	-	-	-	-
H-23	603	-	663	3.9	$1\frac{1}{2}$	1.4
Bldg. 23	-	-	-	-	-	-
H-41	567	-	623	3.8	$1\frac{1}{2}$	1.4
Bldg. 41	-	-	-	-	-	-
I-40	567	-	623	3.8	$1\frac{1}{2}$	1.4
Bldg. 40	-	-	-	-	-	-
J-39	567	-	623	3.8	$1\frac{1}{2}$	1.4
Bldg. 39	-	-	-	-	-	-
J-36	1,228	-	1,350	7.9	$2\frac{1}{2}$	1.1
Bldg. 36	-	-	-	-	-	-
KW	453	-	498	2.9	$1\frac{1}{2}$	1.1
W-49	192	-	211	1.2	$1\frac{1}{4}$	0.2
Bldg. 49	-	-	-	-	-	-
W-24	261	-	287	1.7	$1\frac{1}{4}$	0.7
Bldg. 24	-	-	-	-	-	-
L-51	115	-	127	.75	1	0.2
Bldg. 51	-	-	-	-	-	-
N-48	335	-	368	2.2	$1\frac{1}{4}$	1.2
Bldg. 48	-	-	-	-	-	-
O-50	903	-	992	5.8	2	1.2
Bldg. 50	-	-	-	-	-	-
P-38	220	-	242	1.4	$1\frac{1}{4}$	0.4
Bldg. 38	-	-	-	-	-	-
P-47	1,911	-	2,110	12.4	$2\frac{1}{2}$	1.7
Bldg. 47	-	-	-	-	-	-

(1) Group II Bldg. Pipe Section	(8) Fric. Res. in. of water/ ft	(9) Straight Pipe Length ft	(10) Equiv. Straight Pipe Length ft	(11) Section Fric. Res. in. of water	(12) Section Starting Point Letter	(13) Circuit Fric. Res. in. of water
U-29, 30	.135	130	165	22	U	402
Bldgs. 29,30	-	-	-	380	29, 30	380
GV	.066	440	475	31	G	413
V-25, 26	.135	130	165	22	V	382
Bldgs. 25, 26	-	-	-	360	25, 26	360
H-23	.070	232	365	26	H	481
Bldg. 23	-	-	-	355	23	355
H-41	.068	180	212	14	H	379
Bldg. 41	-	-	-	365	41	365
I-40	.068	180	212	14	I	354
Bldg. 40	-	-	-	340	40	340
J-39	.068	180	212	14	J	339
Bldg. 39	-	-	-	325	39	325
J-36	.020	680	718	15	J	340
Bldg. 36	-	-	-	325	36	325
KW	.041	228	258	11	K	332
W-49	.019	50	57	1	W	321
Bldg. 49	-	-	-	320	49	320
W-24	.307	140	150	6	W	321
Bldg. 24	-	-	-	315	24	315
L-51	.024	308	330	8	L	313
Bldg. 51	-	-	-	305	51	305
N-48	.058	888	940	55	N	445
Bldg. 48	-	-	-	390	48	390
O-50	.034	120	130	4	O	409
Bldg. 50	-	-	-	405	50	405
P-38	.024	248	280	7	P	392
Bldg. 38	-	-	-	385	38	385
P-47	.047	776	845	40	P	390
Bldg. 47	-	-	-	350	47	350

(1) Group II Bldg. Pipe Section	(14) Supply Heat Losses Btu/hr/ft	(15) Supply Section Temp. Drop F	(16) Supply Section Ending Temp. F	(17) Supply Section Press. Drop psi	(18) Supply Section Ending Press. psig	(19) Corres. Sat. Temp. F
U-29, 30	90	.49	385.7	.3	212.8	392.6
Bldgs. 29, 30	-	-	-	9.5	203.3	389.0
GV	105	.98	385.5	.5	212.8	392.7
V-25, 26	90	.49	385.0	.3	212.5	392.6
Bldgs. 25, 26	-	-	-	9.5	203.0	388.9
H-23	76	2.26	382.8	.4	212.4	392.6
Bldg. 23	-	-	-	9.5	202.9	388.9
H-41	77	1.83	383.3	.3	212.5	392.5
Bldg. 41	-	-	-	9.5	203.0	388.9
I-40	77	1.83	382.2	.3	212.1	392.4
Bldg. 40	-	-	-	9.5	202.6	388.8
J-39	77	1.83	380.8	.3	211.8	392.3
Bldg. 39	-	-	-	9.5	202.3	388.7
J-36	95	4.09	378.5	.3	211.8	392.3
Bldg. 36	-	-	-	9.5	202.3	388.7
KW	74	2.91	376.5	.2	211.8	392.3
W-49	70	1.46	375.0	.0	211.8	392.3
Bldg. 49	-	-	-	9.5	202.3	388.7
W-24	70	2.88	373.4	.1	211.7	392.3
Bldg. 24	-	-	-	9.5	202.6	388.8
L-51	55	11.32	354.6	.1	211.6	392.2
Bldg. 51	-	-	-	9.5	202.1	388.6
N-48	72	14.5	372.2	.9	212.9	392.7
Bldg. 48	-	-	-	9.5	203.4	389.1
O-50	88	.91	384.7	.1	213.1	392.8
Bldg. 50	-	-	-	9.5	203.6	389.2
P-38	72	6.38	378.3	.1	212.9	392.7
Bldg. 38	-	-	-	9.5	203.4	389.1
P-47	94	2.94	381.8	.6	212.4	392.6
Bldg. 47	-	-	-	9.5	202.9	388.9

(1) Group II Bldg. Pipe Section	(2) Design Bldg. Heat Load MBtu/hr	(3) 30 Percent Allowance for Main Expansion MBtu/hr	(4) 10 Percent Allowance System Losses MBtu/hr	(5) Heat Load mlbs Water/hr	(6) Pipe Size in.	(7) HTW Vel. fps
Q-20	562	-	618	3.6	$1\frac{1}{2}$	1.3
Bldg. 20	-	-	-	-	-	-
Q-37	188	-	207	1.2	$1\frac{1}{4}$	0.2
Bldg. 37	-	-	-	-	-	-

(1) Group II Bldg. Pipe Section	(8) Fric. Res. in. of water/ ft	(9) Straight Pipe Length ft	(10) Equiv. Straight Pipe Length ft	(11) Section Fric. Res. in. of water	(12) Section Starting Point Letter	(13) Circuit Fric. Res. in. of water
Q-20	.060	324	355	21	Q	376
Bldg. 20	-	-	-	355	20	355
Q-37	.020	176	197	4	Q	374
Bldg. 37	-	-	-	370	37	370

(1) Group II Bldg. Pipe Section	(14) Supply Heat Losses Btu/ hr/ft	(15) Supply Section Temp. Drop F	(16) Supply Section Ending Temp. F	(17) Supply Section Press. Drop. psi	(18) Supply Section Ending Press. psig	(19) Corres. Sat. Temp. F
Q-20	74	3.33	3.79	.4	212.3	392.6
Bldg. 20	-	-	-	9.5	202.8	388.8
Q-37	70	5.13	377.8	.1	212.6	392.6
Bldg. 37	-	-	-	9.5	203.1	388.9

(1) Group I Bldg. Pipe Section	(2) Design Bldg Heat Load MBtu/hr	(3) 30 Percent Allowance for Main Expansion MBtu/hr	(4) 10 Percent Allowance System Losses MBtu/hr	(5) Heat Load mlbs water/ hr	(6) Pipe Size in.	(7) HTW Vel. fps
AB	19,252	25,000	27,500	162	6	3.8
BC	17,623	22,900	25,200	148	5	5.1
CD	17,143	22,300	24,500	144	5	5.0
DE	16,074	20,900	23,000	135	5	4.7
EF	14,569	18,900	20,800	122	5	4.2
FG	14,246	18,500	20,400	120	5	4.1
GH	12,962	16,800	18,500	109	5	3.7
HI	6,827	8,880	9,770	58	4	3.0
IJ	517	672	739	4.4	$1\frac{1}{2}$	1.7
J-12	228	-	251	1.5	$1\frac{1}{4}$	0.5
Bldg. 12	-	-	-	-	-	-
BL	1,629	2,120	2,330	13.7	2	2.7
LM	938	1,220	1,340	7.9	$1\frac{1}{4}$	4.3
MN	585	760	835	4.9	$1\frac{1}{4}$	2.7
N-45	225	-	247	1.5	1	1.3
Bldg. 45	-	-	-	-	-	-
L-43	691	-	760	4.5	1	3.9
Bldg. 43	-	-	-	-	-	-
M-42	353	-	388	2.3	1	1.9
Bldg. 42	-	-	-	-	-	-
N-44	360	-	396	2.3	1	1.9
Bldg. 44	-	-	-	-	-	-
C-10	479	-	527	3.1	1	2.7
Bldg. 10	-	-	-	-	-	-
DO	1,069	-	1,175	6.9	$1\frac{1}{4}$	3.7
O-8	666	-	733	4.3	1	3.7
Bldg. 8	-	-	-	-	-	-
O-9	403	-	444	2.6	1	2.2
Bldg. 9	-	-	-	-	-	-
E-4	575	-	633	3.7	1	3.1
Bldg. 4	-	-	-	-	-	-

(1) Group I Bldg. Pipe Section	(8) Fric. Res. in. of water/ ft	(9) Straight Pipe Length ft	(10) Equiv. Straight Pipe Length ft	(11) Section Fric. Res. in. of water	(12) Section Starting Point Letter	(13) Circuit Fric. Res. in. of water
AB	.078	680	795	62	A	1,996
BC	.169	1,920	2,190	370	B	1,934
CD	.159	740	860	137	C	1,564
DE	.138	1,780	2,030	280	D	1,427
EF	.112	670	760	85	E	1,147
FG	.110	560	650	72	F	1,062
GH	.092	1,280	1,460	134	G	990
HI	.079	1,640	1,820	144	H	856
IJ	.088	1,176	1,280	113	I	712
J-12	.030	270	305	9	J	599
Bldg. 12	-	-	-	590	12	590
BL	.148	1,770	1,950	289	B	1,933
LM	.630	780	840	530	L	1,644
MN	.270	760	810	219	M	1,114
N-45	.090	530	555	50	N	895
Bldg. 45	-	-	-	845	45	845
L-43	.700	60	70	49	L	1,644
Bldg. 43	-	-	-	1,595	43	1,595
M-42	.195	60	70	14	M	1,114
Bldg. 42	-	-	-	1,100	42	1,100
N-44	.195	60	70	14	N	894
Bldg. 44	-	-	-	880	44	880
C-10	.340	120	155	53	C	1,563
Bldg. 10	-	-	-	1,510	10	1,510
DO	.457	165	195	89	D	1,425
O-8	.640	140	165	106	O	1,336
Bldg. 8	-	-	-	1,230	8	1,230
O-9	.240	2,410	2,770	665	O	1,335
Bldg. 9	-	-	-	670	9	670
E-4	.460	430	465	214	E	1,149
Bldg. 4	-	-	-	935	4	935

(1) Group I Bldg. Pipe Section	(14) Supply Heat Losses Btu/hr/ft	(15) Supply Section Temp. Drop F	(16) Supply Section Ending Temp. F	(17) Supply Section Press. Drop. psi	(18) Supply Section Ending Press. psig	(19) Corres. Sat. Temp. F
AB	140	.29	389.7	1.0	237.0	401.5
BC	120	.89	388.8	5.8	231.2	399.4
CD	118	.30	388.5	2.1	229.1	398.8
DE	118	.78	387.7	4.3	224.8	397.1
EF	117	.32	387.4	1.3	223.5	396.8
FG	117	.27	387.1	1.2	222.3	396.6
GH	117	.69	386.4	2.1	220.2	395.4
HI	116	1.64	384.8	2.3	217.9	394.5
IJ	78	10.42	374.4	1.8	216.1	393.8
J-12	65	5.84	368.6	.1	216.0	393.8
Bldg. 12	-	-	-	9.5	206.5	390.3
BL	92	5.95	383.7	4.3	232.7	399.9
LM	70	3.46	380.2	8.3	224.4	397.0
MN	68	5.27	374.9	3.3	221.1	395.8
N-45	62	10.95	364.0	.8	220.3	395.4
Bldg. 45	-	-	-	9.5	210.8	391.9
L-43	65	.43	383.3	.8	231.9	399.8
Bldg. 43	-	-	-	9.5	221.4	395.9
M-42	65	.85	378.4	.2	224.2	396.9
Bldg. 42	-	-	-	9.5	214.7	393.5
N-44	65	.85	374.1	.2	220.9	395.8
Bldg. 44	-	-	-	9.5	211.4	392.1
C-10	69	1.34	387.5	1.1	230.1	399.1
Bldg. 10	-	-	-	9.5	220.6	395.5
DO	73	.87	387.6	1.4	227.7	398.0
O-8	69	1.12	386.5	1.8	226.9	397.4
Bldg. 8	-	-	-	9.5	217.4	394.4
O-9	69	32.0	355.6	10.4	217.3	394.4
Bldg. 9	-	-	-	9.5	207.8	390.9
E-4	68	3.96	383.7	3.2	221.6	396.2
Bldg. 4	-	-	-	9.5	212.1	392.4

(1) Group I Bldg. Pipe Section	(2) Design Bldg. Heat Load MBtu/hr	(3) 30 Percent Allowance for Main Expansion MBtu/hr	(4) 10 Percent Allowance System Losses MBtu/hr	(5) Heat Load mlbs water/ hr	(6) Pipe Size in.	(7) HTW Vol. fps
E-7	930	-	1,025	6.0	1	5.2
Bldg. 7	-	-	-	-	-	-
F-3	323	-	355	2.1	1	1.8
Bldg. 3	-	-	-	-	-	-
G-1	948	-	1,042	6.1	$1\frac{1}{4}$	3.3
Bldg. 1	-	-	-	-	-	-
G-2	336	-	370	2.2	1	1.8
Bldg. 2	-	-	-	-	-	-
H-6	6,135	-	6,740	39.7	$2\frac{1}{2}$	5.3
Bldg. 1	-	-	-	-	-	-
I-5	6,310	-	6,950	40.9	$2\frac{1}{2}$	5.6
Bldg. 5	-	-	-	-	-	-
J-11	289	-	318	1.9	1	1.6
Bldg. 11	-	-	-	-	-	-

(1) Group I Bldg. Pipe Section	(8) Fric. Res. in. of water/ ft	(9) Straight Pipe Length ft	(10) Equiv. Straight Pipe Length ft	(11) Section Fric. Res. in. of water	(12) Section Starting Point Letter	(13) Circuit Fric. Res. in. of water
E-7	1.15	140	170	196	E	1,146
Bldg. 7	-	-	-	950	7	950
F-3	.160	60	65	11	F	1,061
Bldg 3	-	-	-	1,050	3	1,050
G-1	.390	595	640	250	G	990
Bldg. 1	-	-	-	740	1	740
G-2	.170	520	565	96	G	991
Bldg. 2	-	-	-	895	2	895
H-6	.410	80	90	37	H	857
Bldg. 6	-	-	-	820	6	820
I-5	.430	80	90	39	I	714
Bldg. 5	-	-	-	675	5	675
J-11	.140	80	90	13	J	598
Bldg. 11	-	-	-	585	11	585

(1) Group I Bldg. Pipe Section	(14) Supply Heat Losses Btu/hr/ft	(15) Supply Section Temp. Drop F	(16) Supply Section Ending Temp. F	(17) Supply Section Press. Drop psi	(18) Supply Section Ending Press. psig	(19) Corres. Sat. Temp. F
E-7	68	.79	386.9	3.1	221.7	396.2
Bldg. 7	-	-	-	9.5	212.2	392.4
F-3	68	.97	386.4	.2	223.3	396.7
Bldg. 3	-	-	-	9.5	213.8	393.1
G-1	73	3.66	383.4	4.0	218.3	394.7
Bldg. 1	-	-	-	9.5	208.8	391.3
G-2	68	8.04	379.1	1.6	220.7	395.6
Bldg. 2	-	-	-	9.5	211.2	392.1
H-6	96	.10	386.3	.6	219.6	395.1
Bldg. 6	-	-	-	9.5	210.1	391.7
I-5	96	.09	384.7	.6	217.3	394.4
Bldg. 5	-	-	-	9.5	207.8	390.9
J-11	62	1.30	373.1	.2	215.9	393.9
Bldg. 11	-	-	-	9.5	206.4	390.3

A. Distribution system heat losses

Table 29 HTW Piping Heat Losses

		Full Load Conditions		No Load Conditions	
Pipe Size in.	Length ft	Average Heat Loss Btu/hr/ft	Total Heat Loss Btu/hr	Average Heat Loss Btu/hr/ft	Total Heat Loss Btu/hr
6	10,820	(140+56)/2 = 98	1,060,000	(140+120)/2 = 130	1,405,000
5	8,790	(120+50)/2 = 85	747,000	(120+105)/2 = 113	994,000
4	3,820	(120+50)/2 = 85	325,000	(120+105)/2 = 113	432,000
$3\frac{1}{2}$	1,120	(114+48)/2 = 81	91,000	(114+ 99)/2 = 107	120,000
3	1,640	(108+46)/2 = 77	126,000	(109+ 94)/2 = 101	166,000
$2\frac{1}{2}$	4,920	(99 +42)/2 = 71	350,000	(99 + 85)/2 = 94	463,000
2	4,010	(92 +39)/2 = 66	264,000	(92 + 78)/2 = 85	341,000
$1\frac{1}{2}$	2,500	(80 +34)/2 = 57	143,000	(80 + 68)/2 = 74	185,000
$1\frac{1}{4}$	5,180	(75 +31)/2 = 53	275,000	(75 + 64)/2 = 70	362,000
1	5,094	(70 +29)/2 = 50	255,000	(70 + 60)/2 = 65	331,000
Buried distribution piping losses			3,636,000		4,799,000
Estimated equipment room losses			500,000		500,000
Total distribution heat losses			4,136,000		5,299,000

Percent of heat losses in the HTW distribution system = (4,136 mbtu/hr)100/(65,000 mbtu/hr = 6.35%

It can be noted that distribution heat losses under winter design, no load condition, should it ever exist, would only be 5,299 mbtu/hr total or 29 percent greater than full load losses. During the summer period the heat losses would tend to be reduced due to the effect of higher ground and air ambient temperatures but would tend to be increased due to higher return water temperatures. These two factors will tend to balance each other and it is concluded that summer and winter piping heat distribution losses will be approximately equal.

B. Heat capacity of the HTW Supply Piping

Table 30 Heat Capacity of the HTW Supply Piping

Pipe Size in.	Supply Piping Volume cu-ft	Average Supply Temp. F	Enthalpy of Supply HTW Btu/cu-ft	Enthalpy of Return HTW Btu/cu-ft	Enthalpy Diff. Btu/cu-ft	Supply Heat Capacity & Btu
6	1,084	389	19,650	11,220	8,430	9,150,000
5	612	387	19,550	11,220	8,330	5,100,000
4	170	385	19,460	11,220	8,240	1,400,000
$3\frac{1}{2}$	39	384	19,420	11,220	8,200	315,000
3	42	384	19,420	11,220	8,200	345,000
$2\frac{1}{2}$	82	382	19,340	11,220	8,120	665,000
2	47	380	19,250	11,220	8,030	375,000
$1\frac{1}{2}$	18	380	19,250	11,220	8,030	140,000
$1\frac{1}{4}$	27	378	19,160	11,220	7,940	215,000
1	16	375	19,020	11,220	7,800	120,000
						17,825,000

The effective stored heat capacity is all contained within the supply half of the distribution system. Heat capacity equals 17,825,000 Btu under winter design conditions. Heat capacity is calculated based on a discharge temperature of 220 F and the average supply temperature for each size of pipe.

IV. Calculations for Sizing of HTW System Pumps

Distribution system frictional resistance = 166 ft

Heating plant frictional resistance (estimated) = 30 ft

Total resistance = 196 ft of water

Capacity of the pumps at full load

Q = pump capacity (gpm)

H = total design heating load (Btu/hr)

Q = H/(design temp. diff.)(8.33 lb/gal)(60 min/hr)
(spec. heat)

Q = (65,000,000 Btu/hr)/(170 F)(8.33)(60)(1 Btu/lb F)

Q = 765 gpm at 62 F

Water Temperature F	Water Density lb/cu-ft	Water Flow Rate gpm
62	62.344	765
220	59.630	799
370	54.855	869
390	54.054	882

Q = 765 gpm (62.344/59.630)

Q = 799 gpm @ 220 F

Two pumps are selected and paralleled so that either pump will deliver 800 gpm at 220 F against a 196 ft head. The second pump is for standby.

Horsepower requirements at full load are determined to be 50 hp.

HP = (flow rate lb/hr)(ft of head)(1 HP min/33,000 ft-lb)
(1 hr/60 min)(1/pump efficiency)

HP = (382,000 lb/hr)(196 ft)(HP min/33,000 ft-lb)
(hr/60 min)(1/.78)

HP = 48.5

V. Calculations for Determining the Supply Heating Load on an Annual Basis

A. Domestic hot water

Btu/yr = (115,620 gal/day)(365 day/yr)(62.4 lb/ft^3)

(1 Btu/lb F)(90 F)/(7.48 gal/ft^3)

= 31,650,000,000 Btu/yr

B. Process steam buildings 20

Btu/yr = (125,400 Btu/hr)(2 hr/day)(365 day/yr)

= 91,500,000 Btu/yr

C. Process steam building 33

Btu/yr = (970,000 Btu/hr)(8 hr/day)(365 day/yr)

= 2,855,000,000 Btu/yr

D. Process steam building 36

Btu/yr = (1,594,000 Btu/hr)(8 hr/day)(260 day/yr)

= 3,320,000,000 Btu/yr

E. Building heating

Btu/yr = (Btu/hr)(degree days)(24 hr/day)/(design temp diff.)

= (30,618,000)(7,500)(24)/(80)

= 68,900,000,000 Btu/yr

F. Steam alternative distribution system losses

Btu/yr = (6,400,000 Btu/hr)(24 hr/day)(365 day/yr)

= 56,000,000,000 Btu/yr

G. HTW alternative distribution system

Btu/yr = (4.100,000 Btu/hr)(24 hr/day)(365 day/yr)

= 35,900,000,000 Btu/yr

H. Total supply heating load

Table 31 Summary of Annual Supply Heating Loads*

Requirement	Steam x 10^6 Btu/yr	HTW x 10^6 Btu/yr
Domestic hot water	31,650	31,650
Process steam	6,267	2,947
Building heating	68,900	68,900
Distribution losses	56,000	35,900
	162,817,000,000 Btu/yr	139,397,000,000 Btu/yr

* Does not include plant auxiliary heating load

VI. Calculations for Determining Central Heating Plant Auxiliary Heating Load

A. Atomization steam for steam alternative

Estimated to be 1.0 percent of supply steam

Design Btu/hr = (.01)(72,250 lb/hr)(960 Btu/lb)

= 693,000 Btu/hr

Annual Btu/yr = (.01)(162.8 x 10^9 Btu/yr)

= 1.63 x 10^9 Btu/yr

B. Atomization steam for HTW alternative

Estimated to be 1.0 percent of supply HTW

Design Btu/hr = (.01)(65,000,000 Btu/hr)

= 650,000 Btu/hr

Annual Btu/yr = (.01)(139.4 x 10^9 Btu/yr)

= 1.40 x 10^9 Btu/yr

C. Blowdown for steam alternative

Estimated to be 1.5 percent of supply steam

Design Btu/hr = (.015)(72,250 lb/hr)(960 Btu/lb)

= 1,060,000 Btu/hr

Annual Btu/yr = (.015)(162.8 x 10^9 Btu/yr)

= 2.42 x 10^9 Btu/yr

D. Blowdown for HTW alternative

Estimated to be negligible

E. Soot blowing for steam alternative

Estimated to be 0.5 percent of supply steam

Design Btu/hr = (.005)(72,250 lb/hr)(960 Btu/lb)

= 346,500 Btu/hr

Annual Btu/yr = (.005)(162.8 x 10^9 Btu/yr)

= .82 x 10^9 Btu/yr

F. Soot blowing for HTW alternative

Estimated to be 0.3 percent of supply HTW

Design Btu/hr = (.003)(65,000,000 Btu/hr)

= 195,000 Btu/hr

Annual Btu/yr = (.003)(139.4 x 10^9 Btu/yr)

= .40 x 10^9 Btu/yr

G. Transmission trapping losses for steam alternative

Calculated to be 1.66 percent of supply steam.

Design Btu/hr = (.0166)(72,250 lb/hr)(960 Btu/lb)

= 1,151,000 Btu/hr

Annual Btu/yr = (.0166)(162.8 x 10^9 Btu/yr)

= 2.70 x 10^9 Btu/yr

H. Transmission trapping losses for HTW alternative

There are no traps in the HTW transmission system.

I. Leaks and losses of the steam alternative

Estimated to be 2.0 percent of supply steam

Design Btu/hr = (.02)(72,250 lb/hr)(960 Btu/lb)

= 1,386,000 Btu/hr

Annual Btu/yr = (.02)(162.8 x 10^9 Btu/yr)

= 3.26 x 10^9 Btu/yr

J. Leaks and Losses of the HTW alternative

Estimated to be negligible

K. Make-up water for the steam alternative

Table 32

Summary of Make-up Water Requirements for the Steam Alternative

Requirement	lb steam/hr	MBtu/hr	Btu/yr x 10^9
Atomization	723	693	1.63
Blowdown	1,083	1,060	2.42
Soot blowing	361	346	.82
Trapping losses	1,200	1,151	2.70
Leaks and losses	1,446	1,386	3.26
	4,813 lb/hr	4,636,000 Btu/hr	10.83 x 10^9 Btu/hr

L. Feedwater heater steam for the steam alternative

72,250 lb/hr - 1,200 lb/hr = 71,050 lb/hr system return at 180 F

4,813 lb/hr make up water at 50 F

Steam rate = (71,050 lb/hr)(1 Btu/lb F)(30 F)/(960 Btu/lb) +

(4,813 lb/hr)(1 Btu/lb F)(160 F)(960 Btu/lb)

= 3,023 lb steam hr

Design Btu/hr = (3,023 lb/hr)(960 Btu/lb)

= 2,900,000 Btu/hr

Annual Btu/yr = $(162.8 \times 10^9$ Btu/yr)(2,900,000 Btu/hr)/
(69,300,000 Btu/hr)
= 6.81×10^9 Btu/hr

M. Fuel heating for the steam alternative

Fuel burning rate = (74,800,000 Btu/hr)/(152,000 Btu/lb)
(8 lb/gal)(.81)
= 75.9 gal/hr design

Fuel circulation rate = 300 gal/hr

Design lb/hr = (300 gal/hr)(8 lb/gal)(.5 Btu/lb F)
(200 F - 40 F)/(960 Btu/lb)
= 200 lb steam/hr

Design Btu/hr = (200 lb/hr)(960 Btu/lb)
= 192,000 Btu/hr

Annual Btu/yr = $(162.8 \times 10^9$ Btu/yr)(192,000 Btu/hr)/
(69,300,000 Btu/hr)
= $.45 \times 10^9$ Btu/yr

N. Fuel heating for the HTW alternative

Fuel burning rate = (66,000,000 Btu/hr)/(152,000 Btu/lb)
(8 lb/gal)(.82)
= 64.1 gal/hr design

Fuel circulation rate = 250 gal/hr

Design lb/hr = (250 gal/hr)(8 lb/gal)(15 Btu/lb F)
(200 F - 40 F)/(960 Btu/lb)
= 167 lb steam/hr

Design Btu/hr = (167 lb/hr)(960 Btu/hr)
= 160,000 Btu/hr

$$\text{Annual Btu/yr} = (139.4 \times 10^9 \text{ Btu/yr})(160{,}000 \text{ Btu/hr})/(65{,}000{,}000 \text{ Btu/hr})$$

$$= .34 \times 10^9 \text{ Btu/yr}$$

O. Steam generation requirements for the steam alternative

Table 33 Summary of Design Steam Generation Requirements for the Steam Alternative

Requirement	lb steam/hr	MBtu/hr	Btu/yr x 10^9
Supply	72,250	69,300	162.82
Fuel heating	200	192	.45
Atomization	723	693	1.63
Soot blowing	361	346	.82
Feedwater heating	3,023	2,900	6.81
Leaks and losses	1,446	1,386	3.26
	78,003 lb/hr	74,817,000 Btu/hr	175.79 x 10^9 Btu/yr

P. Auxiliary load for the steam alternative

5,753 lb steam/hr design

5,530,000 Btu/hr design

12,970,000,000 Btu/yr

Q. Heating requirements for the HTW alternative

Table 34 Summary of Design Heating Requirements for the HTW Alternative

Requirement	MBtu/hr	Btu/yr x 10^9
Supply	65,000	139.40
Fuel heating	160	.34
Atomization	650	1.40
Soot blowing	195	.40
	66,005,000 Btu/hr	141,540,000,000 Btu/yr

R. Auxiliary load for the HTW alternative

1,005,000 Btu/hr design

2,140,000,000 Btu/yr

S. Summer auxiliary load for the steam alternative

MBtu/hr = (5,530 MBtu/hr)(17,800 MBtu/hr)/(48,400 MBtu/hr)

= 2,038 MBtu/hr

T. Summer auxiliary load for the HTW alternative

MBtu/hr = (1,005 MBtu/hr)(16,200 MBtu/hr)/(46,800 MBtu/hr)

= 348 MBtu/hr

VII. Summary of Pipe Requirements

Table 35 Summary of Pipe Requirements for the Heating Distribution System Alternatives

Pipe Size in.	Cu-ft/ft of pipe	Pipe Length Required feet			Inside Pipe Volume cu-ft		
		Steam	Cond.	HTW	Steam	Cond.	HTW
10	.5475	3,400	-	-	1,860	-	-
8	.3475	1,190	-	-	413	-	-
6	.2005	4,225	-	10,820	846	-	2,168
5	.1391	2,180	-	8,790	303	-	1,223
4	.0889	1,210	4,364	3,820	108	388	340
3½	.0687	80	190	1,120	6	13	77
3	.0513	2,157	4,225	1,640	111	218	84
2½	.0333	2,013	1,260	4,920	67	42	164
2	.0233	7,423	2,780	4,010	173	65	94
1½	.0141	-	4,425	2,500	-	62	35
1¼	.0104	-	1,264	5,180	-	13	54
1	.0060	-	5,370	5,094	-	32	31
		23,878	23,878	47,894*	3,887	833	4,270*

* HTW pipe lengths and volumes are divided evenly between supply and return portions of the distribution system.

VIII Recommended Material Specifications

Table 36 Sample Material Specifications for Steam or HTW Piping

Item		Specification
Pipe material		ASTM A53 Grade A seamless or lapwelded
Minimum thickness		Sch. 40
Minimum thickness for lines 2" and smaller		Sch. 80*
Minimum pipe size		$\frac{1}{2}$"
Type of joints $2\frac{1}{2}$" and larger		Flanged or welded
Type of joints 2" and smaller		Screwed and seal welded or socket welded
Butt weld joints per engineers standard log		M 507 or M 508 as applicable
Welding fittings and forgings		Thickness equal to pipe (min), ASTM A181 Grade 1
Flanged fittings and castings		ASTM A216 Grade WCA or WCB
Pressure class		ASA 300 lb
Flange facing		Raised face fine serrated finish
Gaskets		Flexatalic type CG
Bolt studs		ASTM A193 Grade B7
Nuts		ASTM A194 Grade 2H
Valves $2\frac{1}{2}$" and larger	Body Material	ASTM A216 Grade WCA or WCB
	Pressure Class	ASA 300 lb
	Bonnet $2\frac{1}{2}$" - 4"	Bolted
	Bonnet 5" and up	Bolted
Valves 2" and Smaller	Class	ASA 600 lb
	Material	ASTM A181 Grade 1
	Bonnet	Bolted
Valve internals and trim		Alloy steel
Bypass required on gate valves larger than		8"

* Schedule 40 costs and dimensions are utilized in this thesis.

APPENDIX C

Calculations for Heating System Costs

I. Data for Calculating Fixed Costs

Table 37 Pipe and Fittings Costs [22,23]

Pipe Size in.	Straight Pipe $/ft	90 Deg. Elbow $ ea.	Tee Red. $ ea.	Reducer Conc. $ ea.	45 Deg. Elbow $ ea.	Valves $ ea.
1	.22	.86	3.10	1.15	.67	9.60
$1\frac{1}{4}$	.29	1.03	4.14	1.54	.79	11.40
$1\frac{1}{2}$	.34	1.25	5.23	1.54	.97	13.00
2	.46	1.56	7.21	1.74	1.21	16.80
$2\frac{1}{2}$	.58	2.51	10.49	1.94	1.94	26.60
3	.90	3.62	13.67	2.33	2.81	37.20
$3\frac{1}{2}$	.94	5.63	18.77	3.12	4.38	52.00
4	.99	5.63	18.77	3.12	4.38	76.00
5	1.14	12.74	42.46	6.28	9.92	129.20
6	1.50	12.74	42.46	6.28	9.92	129.20
8	3.90	23.94	68.25	9.43	18.63	214.20
10	5.55	49.84	121.04	14.85	37.33	-

A. Cost for straight pipe runs

Estimate the pipe cost per 1000 ft of pipe run including all fitting and pipe costs for expansion loops. Consider 1 to 6 in. pipe is anchored each 200 ft and 8 to 10 in. pipe is anchored each 250 ft.

10 in. pipe, 1000 ft @ $5.55	$5,550.00
4-10 in. ells/exp. loop (4 exp. loops) @ $49.84	797.00
10 in. pipe 60 ft/exp. loop (4 exp. loops) @ $5.55	1,333.00
Total pipe cost for 1000 ft run	$7,680.00

Fitting costs including tees, caps, reducers, flanges, crosses, valves, air bottles, saddles, sleeves, etc., are estimated separately and are added to the total pipe costs figured for each pipe size's length of run.

B. Cost for trenching and back filling

The average trench excavation is 3 ft deep times 2 ft-6 in. wide. Both the steam and HTW alternatives will require 23,900 ft of trenching.

$$\text{Volume} = (3\ \text{ft})(2.5\ \text{ft})(23{,}900\ \text{ft})/(27\ \text{cu-ft/cu-yd})$$
$$= 6{,}640\ \text{cu-yd}$$
$$\text{Cost} = (6{,}640\ \text{cu-yd})(\$3.06/\text{cu-yd})$$
$$= \$20{,}000$$

C. Cost for anchors

Both the steam and HTW alternatives will require approximately 70 pipe anchors between expansion loops in the distribution system

$$\text{Cost} = (70\ \text{anchors})(\$60.00/\text{anchor})$$
$$= \$4{,}200$$

D. Cost for welding pipe

Welding costs presented in Table 38 are figured on a per joint basis according to the size of the pipe.

Table 38 Cost for Welding Pipe

Pipe Size in.	Welding Joints/day	Cost $/joint
1 to 1½	8	12
2 to 3	7	14
3½ to 4	6	16
5	5	20
6	4	25
8	3	35
10	2	50

E. Cost for pipe insulation

Table 39 Quantity of Insulation for Buried Pipes

Nominal Pipe Size in.	Outside Diameter in.	Outside Diameter Area sq-in.	Insulation Section Area sq-in.	Net Insulation Area sq-ft.
1	1.315	1.358	60.8	.412
$1\frac{1}{4}$	1.660	2.164	66.3	.445
$1\frac{1}{2}$	1.900	2.835	70.3	.468
2	2.375	4.430	78.5	.515
$2\frac{1}{2}$	2.875	6.494	87.7	.564
3	3.500	9.618	132	.850
$3\frac{1}{2}$	4.000	12.57	144	.913
4	4.500	15.90	156	.973
5	5.563	24.31	245	1.53
6	6.625	34.48	293	1.80
8	8.625	58.4	404	2.40
10	10.750	90.8	660	3.95

Insulation cost delivered = $125.00/Ton
Density of insulation = 40 lb/cu-ft
Cost of insulation = $2.50/cu-ft

Insulation quantities are calculated for single pipe runs. Actually pipes are run in pairs in trenches. the net insulation saving for the pair of pipes over two separate single pipes is approximately 20 percent by volume. This method is valid for estimating purposes since most of the 20 percent will be required for additional insulation thicknesses required for expansion loops and road crossings. Also it is most probable that the formed trench sizes will be slightly larger than prescribed. The final estimate will be sufficiently accurate for purposes of cost estimate.

II. Calculation of Fixed Costs for the Steam System Alternative

A. Central heating plant fixed costs for the steam alternative

Table 40 Summary of Fixed Central Heating Plant Costs for the Steam Alternative

Item	Cost	Sub-totals
Fuel pump with controls	$ 3,000	
Materials and installation	1,250	
Standby electric heaters	2,000	
	$ 6,250	
25% overhead and profit	1,550	
Fuel handling equipment installed	$ 7,800	$ 7,800
Storage tanks and piping installed		$ 20,000
Cost of boilers	$129,000	
Cost of boiler installation	2,000	
	$131,000	
25% overhead and profit	32,750	
Cost of boilers installed	$163,750	$ 163,750
Cost of controls installed		$ 15,000
Feed water pumps	2,500	
Feed water heater	750	
Water treatment equipment	5,000	
Pipe and fittings	4,000	
Installation costs	4,000	
	$ 16,250	
25% overhead and profit	4,050	
	$ 20,300	$ 20,300
Cost of plant building 4,500 sq-ft @ $35.00/sq-ft		$ 157,500
Plant investment costs		$ 384,350

[illegible]

B. Steam distribution system costs

1. Cost summary for the steam alternative distribution system

Table 41 Summary of Distribution System Costs for the Steam Alternative

Pipe Size in.	Pipe and Fittings $	Pipe Installation $	Welding Pipe $	Insulation Material $	Sub-Totals $
1	1,692	1,692	5,680	5,520	
1¼	584	584	1,705	1,410	
1½	2,089	2,089	5,120	5,180	
2	7,156	7,156	15,480	13,150	
2½	2,547	2,547	3,850	4,610	
3	7,779	7,779	8,130	13,580	
3½	686	686	896	620	
4	7,430	7,430	7,150	13,570	
5	5,630	5,630	3,695	11,400	
6	9,340	9,340	8,330	19,050	
8	6,560	6,560	3,220	7,140	
10	26,370	26,370	12,100	33,600	
	$77,863	$77,863	$75,356	$128,830	$359,912
	Cost for anchors				4,200
	Cost of trenching and backfilling				20,000
	Cost for manhole and equipment*				3,200
	Cost for placing insulation				25,000
	Sub-total				$412,312
	25 percent profit and overhead				103,078
	Steam distribution system cost				$515,390

* The manhole contains the condensate receiver and pump for the long supply main section AB for group II buildings.

2. Pipe fittings summary for the steam alternative distribution system

Table 42 Estimate of Fittings for Each Size Pipe for the Steam Alternative

Pipe Size in.	Elbow 90 Deg.	Tees	Elbow 45 Deg.	Reducer Conc.	Fitting Cost $	Misc. Fitting Cost $	Valves	Valve Cost $
1	64	5	64	-	110	40	21	202
$1\frac{1}{4}$	27	-	18	-	43	7	10	114
$1\frac{1}{2}$	36	5	44	15	133	17	13	169
2	124	12	130	17	467	33	40	672
$2\frac{1}{2}$	4	6	6	22	128	22	4	107
3	6	18	66	22	503	47	4	149
$3\frac{1}{2}$	6	6	8	5	198	2	3	156
4	3	10	20	14	337	13	-	-
5	-	4	-	3	276	24	2	260
6	1	12	-	12	598	2	1	130
8	1	4	-	5	344	6	-	-
10	1	1	1	1	223	27	-	-
5*	-	-	-	1	6	4	2	260
2*	-	-	-	2	4	6	2	34

* This pipe is the section provided for manually looping group II buildings and is normally secured.

3. Pipe and fittings cost for the steam alternative distribution system

Table 43 Total Cost of Piping and Fittings for the Steam Alternative

Pipe Size in.	Pipe Cost $/ft run	Pipe Length ft	Pipe Cost $	Fitting Cost $	Valve Cost $	Total Cost Pipe and Fittings $
1	.25	5,370	1,340	150	202	1,692
1¼	.33	1,264	420	50	114	584
1½	.40	4,425	1,770	150	169	2,089
2	.54	10,203	5,510	500	672	6,682
2½	.70	3,273	2,290	150	107	2,547
3	1.11	6,382	7,080	550	149	7,779
3½	1.22	270	330	200	156	686
4	1.27	5,574	7,080	350	-	7,430
5	1.61	2,180	3,510	300	260	4,070
6	2.04	4,225	8,610	600	130	9,340
8	5.22	1,190	6,210	350	-	6,560
10	7.68	3,400	26,120	250	-	26,370
5*	1.61	800	1,290	10	260	1,560
2*	.54	800	430	10	34	474
				Total Cost		$ 77,863

The estimate of the fitting costs for each size of pipe includes only those fittings located on the distribution system external of either the central heating plant or individual building utility rooms excepting the 90 degree elbows used in the expansion loops. The total expansion loop cost is figured into the ($/ft run) pipe cost.

* This pipe is the section provided for manually looping group II buildings and is normally secured.

4. Welding costs for the steam alternative distribution system

Table 44 Cost of Welding Pipe for the Steam Alternative

Pipe Size in	Pipe Joints	Cost $/Joint	Welding Cost $
1	473	12	5,680
$1\frac{1}{4}$	142	12	1,705
$1\frac{1}{2}$	427	12	5,120
2	1,105	14	15,480
$2\frac{1}{2}$	275	14	3,850
3	581	14	8,130
$3\frac{1}{2}$	56	16	896
4	447	16	7,150
5	185	20	3,695
6	333	25	8,330
8	92	35	3,220
10	242	50	12,100
		Total Cost	$75,356

5. Pipe insulation costs for the steam alternative distribution system

Table 45 Cost of Pipe Insulation for the Steam Alternative

Pipe Size in.	Pipe Length ft	Insulation Section Area sq-ft	Insulation Volume cu-ft	Insulation Cost $
1	5,370	.412	2,210	5,520
$1\frac{1}{4}$	1,264	.445	562	1,410
$1\frac{1}{2}$	4,425	.468	2,070	5,180
2	11,003	.515	5,260	13,150
$2\frac{1}{2}$	3,273	.564	1,840	4,610
3	6,382	.850	5,430	13,580
$3\frac{1}{2}$	270	.913	247	620
4	5,574	.973	5,420	13,570
5	2,980	1.53	4,550	11,400
6	4,225	1.80	7,600	19,050
8	1,190	2.40	2,860	7,140
10	3,400	3.95	13,430	33,600
			Total Cost	$128,830

C. Building utility room costs for the steam alternative distribution system

Table 46 Summary of Utility Room Costs for the Steam Alternative

Control valves	$ 2,000	
Heat exchangers	2,000	
Condensate pump	500	
Other materials	1,000	
Installation	2,000	
	$ 7,500	per room
	44	rooms
	$ 330,000	
3 process steam stations	3,000	
	$ 333,000	
Overhead and profit	83,250	
Total Cost	$ 416,250	

III. Calculation of Fixed Costs for the HTW System Alternative

A. Central heating plant fixed costs for the HTW alternative

Table 47 Summary of Fixed Central Heating Plant Costs for the HTW Alternative

Item	Cost	Sub-totals
Fuel pump with controls	$ 3,000	
Materials and installation	1,250	
Stand by electric heaters	2,000	
	$ 6,250	
25% overhead and profit	1,550	
Fuel handling equipment installed	$ 7,800	$ 7,800
Storage tanks and piping installed		20,000
Cost of boilers	$156,000	
Cost of boiler installation	2,000	
	$158,000	
25% overhead and profit	39,500	
Cost of boilers installed	$197,500	$ 197,500
Cost of controls installed		15,000
Circulation pumps	$ 6,000	
Water treatment equipment	800	
Pipe and fittings	2,000	
Nitrogen pressurization system	5,000	
Installation costs	4,000	
	$ 17,800	
25% overhead and profit	4,450	
	$ 22,250	$ 22,250
Cost of plant building 3,600 sq-ft @ $35.00/sq-ft		$ 126,000
Plant investment costs		$ 388,550

B. HTW distribution system costs

1. Cost summary for the HTW alternative distribution system

Table 48 Summary of Distribution System Costs for the HTW Alternative

Pipe Size in.	Pipe and Fittings $	Pipe Installation $	Welding Pipe $	Insulation Material $	Sub-Totals $
1	1,640	1,640	5,860	5,230	
$1\frac{1}{4}$	2,085	2,085	5,680	5,770	
$1\frac{1}{2}$	1,230	1,230	2,870	2,930	
2	2,763	2,763	5,650	5,160	
$2\frac{1}{2}$	3,909	3,909	5,830	6,940	
3	2,319	2,319	2,390	3,440	
$3\frac{1}{2}$	1,470	1,470	1,310	2,560	
4	7,798	7,798	6,300	13,200	
5	15,000	15,000	13,100	33,580	
6	22,500	22,500	19,690	48,700	
	$60,714	$60,714	$68,680	$127,510	$317,618
	Cost for anchors				4,200
	Cost of trenching and backfilling				20,000
	Cost for 3 manholes*				6,000
	Cost for placing insulation				25,000
	Sub Total				$372,818
	25 percent profit and overhead				93,205
	HTW distribution system cost				$466,023

* The manholes are provided to facilitate draining the HTW distribution system.

2. Pipe fittings summary for the HTW alternative distribution system

Table 49 Estimate of Fittings for Each Size Pipe for the HTW Alternative

Pipe Size in.	Elbow 90 Deg.	Tees	Elbow 45 Deg.	Reducer Conc.	Fitting Cost $	Misc. Fitting Cost $	Valves	Valve Cost $
1	82	-	26	-	90	10	26	250
1¼	56	6	20	4	105	45	18	205
1½	32	4	14	2	78	22	10	130
2	54	4	18	18	166	34	24	403
2½	36	2	12	6	146	4	12	319
3	-	22	4	1	313	37	4	149
3½	-	3	-	-	56	44	-	-
4	-	14	-	1	265	35	4	304
5	2	18	4	2	819	31	-	-
6	6	9	2	4	403	47	-	-
4*	-	-	-	2	6	4	4	304

* This pipe is the section provided for manually looping group II buildings and is normally secured.

3. Pipe and fittings cost for the HTW alternative distribution system

Table 50 Total Cost of Piping and Fittings for the HTW Alternative

Pipe Size in.	Pipe Cost $/ft run	Pipe Length ft	Pipe Cost $	Fitting Cost $	Valve Cost $	Total Cost Pipe and Fittings $
1	.25	5,094	1,290	100	250	1,640
1¼	.33	5,180	1,730	150	205	2,085
1½	.40	2,500	1,000	100	130	1,230
2	.54	4,010	2,160	200	403	2,763
2½	.70	4,920	3,440	150	319	3,909
3	1.11	1,640	1,820	350	149	2,319
3½	1.22	1,120	1,370	100	-	1,470
4	1.27	3,820	4,850	300	304	5,454
5	1.61	8,790	14,150	850	-	15,000
6	2.04	10,820	22,050	450	-	22,500
4*	1.27	1,600	2,030	10	304	2,344
			Total Cost			$ 60,714

The estimate of the fitting costs for each size of pipe includes only those fittings located on the distribution system external of either the central heating plant or individual building utility rooms excepting the 90 degree elbows used in the expansion loops. The total expansion loop cost is figured into the ($/ft run) pipe cost.

* This pipe is the section provided for manually looping group II buildings and is normally secured.

4. Welding costs for the HTW alternative distribution system

Table 51 Cost of Welding Pipe for the HTW Alternative

Pipe Size in.	Pipe Joints	Cost $/joint	Welding Cost $
1	488	12	5,860
1¼	473	12	5,680
1½	239	12	2,870
2	404	14	5,650
2½	416	14	5,830
3	171	14	2,390
3½	82	16	1,310
4	394	16	6,300
5	654	20	13,100
6	787	25	19,690
		Total Cost	$68,680

5. Pipe insulation costs for the HTW alternative distribution system

Table 52 Cost of Pipe Insulation for the HTW Alternative

Pipe Size in.	Pipe Length ft	Insulation Section Area sq-ft	Insulation Volume cu-ft	Insulation Cost $
1	5,094	.412	2,098	5,230
$1\frac{1}{4}$	5,180	.445	2,305	5,770
$1\frac{1}{2}$	2,500	.468	1,171	2,930
2	4,010	.515	2,062	5,160
$2\frac{1}{2}$	4,920	.564	2,775	6,940
3	1,620	.850	1,378	3,440
$3\frac{1}{2}$	1,120	.913	1,022	2,560
4	5,420	.973	5,280	13,200
5	8,790	1.53	13,440	33,580
6	10,820	1.80	19,500	48,700
			Total Cost	$127,510

C. Building utility room costs for the HTW alternative distribution system

Table 53 Summary of Utility Room Costs for the Steam Alternative

Control valves	$ 1,500	
Heat exchangers	2,000	
Other materials	800	
Installation	2,000	
	$ 6,300	per room
	44	rooms
	$ 277,200	
2 process steam stations	4,000	
	$ 281,200	
Overhead and profit	70,300	
Total Cost	$ 351,500	

IV. Calculation of Operating Costs for the Steam System Alternative

A. Calculation of fuel costs for the steam alternative

Efficiency = 81%

Fuel is #6 fuel oil, 152,000 Btu/gal

$/yr = (162,817,000,000 Btu/yr)($.075/gal)/(152,000 Btu/gal)(.81)

= $99,150 per year fuel cost

B. Calculation of water costs for the steam alternative

Make up rate = 4,813 lb/hr

Water cost = $.20 per 1000 gal

$/yr = (4,813 lb/hr)(8,760 hr/yr)($.20/1000 gal)/(8.33 lb/gal)

= $1,013 per year water cost

C. Calculation of operating labor costs for the steam alternative

$/yr = (10 men)($6,000/yr)

= $60,000 per year operating labor cost

D. Calculation of plant maintenance labor costs for the steam alternative

$/yr = (2 men)($6,000/yr)

= $12,000 per year plant maintenance labor cost

E. Calculation of supervision and clerical costs for the steam alternative

One supervisor at	$10,000/yr
Part time clerk at	2,000/yr
Cost	$12,000/yr

F. Calculation of operating material costs for the steam alternative

Estimated to be $3,000/yr

G. Calculation of system maintenance labor costs for the steam alternative

$/yr = (4 men)($6,000/yr)

= $24,000 per year system maintenance labor cost

H. Calculation of plant maintenance material costs for the steam alternative

Estimated to be 10% of labor costs

$/yr = (.10)($12,000)

= $1,200 per year plant maintenance material cost

I. Calculation of system maintenance material costs for the steam alternative

Estimated to be 10% of labor costs

$/yr = (.10)($24,000)

= $2,400 per year system maintenance material cost

J. Calculation of electrical power costs for the steam alternative

1. Plant motors

$/yr = (65HP)(.40)(.7457KW/HP)($.01/KWhr)
(8,760 hr/yr)

=$1,700/yr

2. Condensate pump motors

$/yr = (37 HP)(.20)(.7457KW/HP)($.01/KWhr)
(8,760 hr/yr)

= $483/yr

3. Miscellaneous heating

$/yr = (5 KW)($.01/KWhr)(8,760 hr/yr)

= $437/yr

4. Total electric power cost = $2,620/yr

V. Calculation of Operating Costs for the HTW System Alternative

A. Calculation of fuel costs for the HTW alternative

Efficiency = 82%

Fuel is #6 fuel oil, 152,000 Btu/gal

$/yr = (139,397,000,000 Btu/yr)($.075/gal)/(152,000 Btu/gal)(.82)

= $83,900 per year fuel cost

B. Calculation of water costs for the HTW alternative

Make up rate estimated to be 10 gal/hr

Water cost = $.20 per 1000 gal

$/yr = (10 gal/hr)(8,760 hr/yr)($.20/1000 gal)

= $18 per year water cost

C. Calculation of operating labor costs for the HTW alternative

$/yr = (10 men)($6,000/yr)

= $60,000 per year operating labor cost

D. Calculation of plant maintenance labor costs for the HTW alternative

$/yr = (2 men)($6000/yr)

= $12,000 per year plant maintenance labor cost

E. Calculation of supervision and clerical costs for the HTW alternative

One supervisor at	$10,000/yr
Part time clerk at	2,000/yr
Cost	$12,000/yr

F. Calculation of operating material costs for the HTW alternative

Estimated to be $2,000/yr

G. Calculation of system maintenance labor costs for the HTW alternative

$/yr = (2 men)($6,000/yr)

= $12,000 per year system maintenance labor cost

H. Calculation of plant maintenance material costs for the HTW alternative

Estimated to be 10% of labor costs

$/yr = (.10)($12,000)

= $1,200 per year plant maintenance material costs

I. Calculation of system maintenance material costs for the HTW alternative

Estimated to be 10% of labor costs

$/yr = (.10)($12,000)

= $1,200 per year system maintenance material costs

J. Calculation of electrical power costs for the HTW alternative

1. Plant motors

$/yr = (160 HP)(.46)(.7457 KW/HP)($.01/KWhr)
(8,760hr/yr)

= $4,803/yr

2. Miscellaneous heating

$$\$/yr = (5\ KW)(\$.01/KWhr)(8{,}760\ hr/yr)$$
$$= \$437/yr$$

3. Total electric power cost = $5,240/yr

VI. Calculation of Operating Costs for the Laundry Boiler

Boiler horsepower	50	
Boiler pressure	100	psig
Size . . . 11'-2", 60", 5'-10" high		
Rated capacity from (212 F)	1,725	lbs steam/hr
Btu output (1000 Btu/hr)	1,675	MBtu/hr
EDR steam gross	6,970	
Fuel consumption at rated capacity		
Light oil	15	GPH
Gas 1000 Btu-natural	2,095	GFH
Power requirements		
Blower motor	3	HP
Efficiency overall from 30% to 100% of rating	82	percent

Design heat load = 1,594,000 Btu/hr for the laundry steam

Annual usage = 3,320,000,000 Btu/yr

Fuel cost $= \frac{3{,}320{,}000{,}000(\$.075)}{152{,}000\ (.82)} =$	$ 2,000
Leaks, losses and misc. uses	200
Operator's wages	5,000
Electricity, water and supplies	600
Maintenance labor and material	200
Total cost	$ 8,000 per year

Purchase and Installation cost complete with controls, condensate pump and fuel storage and handling facilities. $10,300